RADIATIONS FROM SLOW RADIUM AND THEIR THERAPEUTIC VALUE

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RADIATIONS
FROM
SLOW-RADIUM

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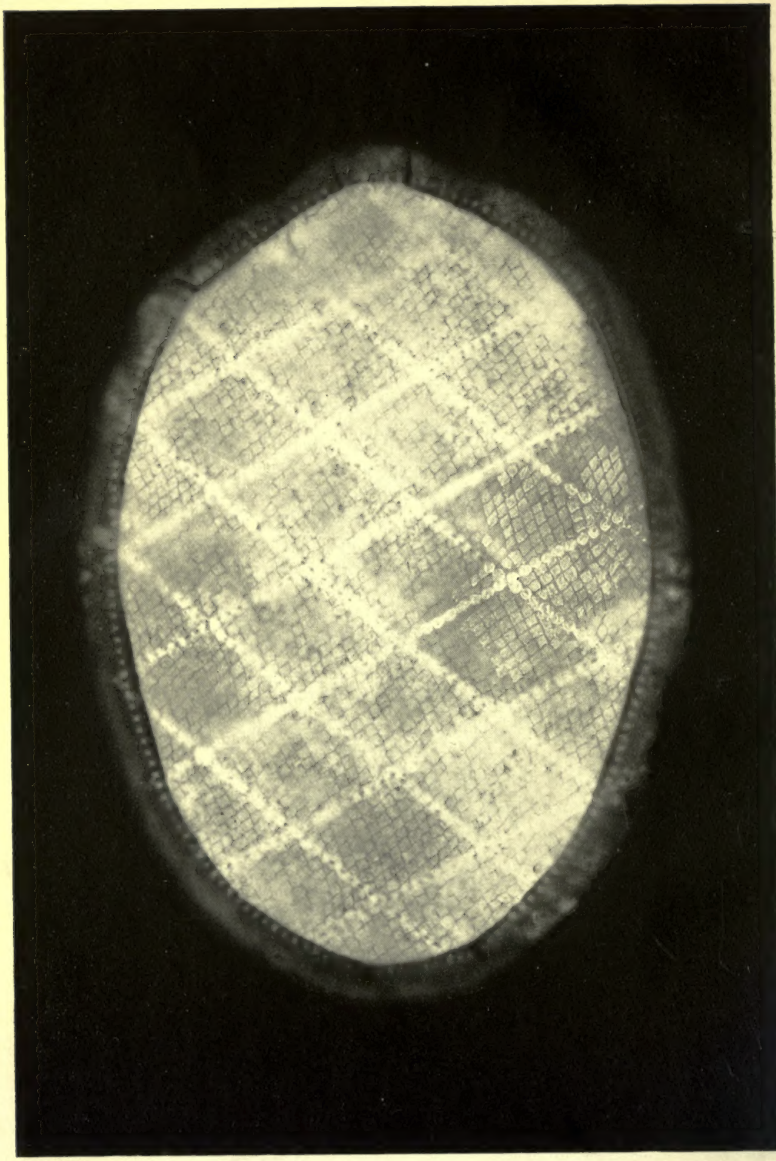

Fig. 9 (See page 20).

Auto-Radiograph of a "Slow-Radium" Applicator
of 33 square inches surface area.

Size of X-Ray Plate, 12in. × 10in.
Time of irradiation, 19 hours.

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RADIATIONS
FROM
SLOW-RADIUM

BY

JOHN B. KRAMER

WITH A NOTE ON

THEIR THERAPEUTIC VALUE

BY

JOHN HALL-EDWARDS
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PREFACE

THE study of Radium and its Radiations has been rendered rather difficult for the Medical Man, owing to the fact that most books published on this subject contain intricate mathematical problems and highly abstract technicalities and fail to give any practical applications.

My object in this volume is to offer to the Medical Profession a concise handbook in the introductory study of the modern Electron Theory, including the principal characteristics and the physical constants of Radium Radiations, simply expressed and amply illustrated.

Further, I hope to enlist more widespread interest and stimulate still more co-operation from our Skin Specialists and the members of the Medical Profession who desire to devote greater individual attention to the treatment of Skin Diseases, Ulcerous Growths, and even muscular or certain kinds of nerve troubles, by means of β Radiations.*

In particular, I wish to draw serious attention to the value of the lesser concentrations of Radium, Uranium and Thorium compounds as an important Therapeutic Agent. The results of a large series of tests which are recorded in this book will, I hope, be sufficient evidence that the strength and action of the Radiations obtained from preparations relatively weak in their Radio-

* One of the best and earliest handbooks on this subject, entitled "RADIUM, ITS PHYSICS AND THERAPEUTICS," was written in 1910 by DAWSON TURNER, M.B., C.M., M.R.C.P. (LOND.), F.R.C.P. (EDIN.), F.R.S.E. The publishers were BAILLIERE, TINDALL AND COX; a second edition was published in 1914.

active properties as compared with pure Radium Salts, are not to be ignored as a potent weapon when employed against the pathological cell. For want of a better name, I have christened the radio-active preparation with which I carried out my experiments "Slow Radium." Briefly, the theory I am about to expound is based upon the destruction, by "Slow-Radium" Radiations, of the pathological cells only and the protection of the living cells below the seat of the disease.

In my view, super-concentration of β Radiations, as is the case with pure Radium Salts, is unnecessary and in most cases highly destructive.

I have endeavoured to show in this book the accumulative effect of the α and β Radiations from "Slow-Radium." Owing to their greatly reduced quantity they do not manifest their powers below the average depth of the skin disease itself, whereas with pure concentrated Radium Radiations, the penetrative powers are three to four times greater, and they kill or damage a considerable volume of living cells below and around the disease which is quite out of proportion to the volume of pathological cells for which the treatment is intended. By reducing the quantities of the irradiating Electrons per second and extending the time of the irradiations over a relatively long period, the desired effect is obtained more definitely than by the methods hitherto applied.

EDGBASTON, JOHN B. KRAMER.
October, 1921.

CHAPTER I.

Introduction

MY object in the present book is to bring to your notice some of the ultimate conclusions I have arrived at after a prolonged endeavour for several years to find a practical and tangible application of that potent force which is liberated by the disintegrating atom from radio-active substances.

I venture to ask that you will follow a few logical arguments based upon certain conclusive experiments which I have carried out in conjunction with Major Hall-Edwards of Birmingham, the well-known X-Ray pioneer and radiographer, who contributes an article on " The Therapeutic Action of Slow Radium."

I have long been of the opinion that we ought to pay greater attention to the wonderful properties of the positive and negative electrons expelled by radio-active substances of moderate strength in the healing of skin diseases.

I owe my thanks to Dr. William Bain, of Minehead, and to Dr. E. T. Selkirk, of Birmingham, who also investigated this subject, and treated several cases which are recorded in the appendix.

The integral features of the methods which I advocate are two-fold:—

In the first instance I aimed at the preparation of a material capable of giving out a sufficient quantity of α, β and γ radiations to produce therapeutic results, which could be applied by Skin Specialists and General Practitioners, without danger to the patient.

In the second instance, I considered it essential to have a sufficient supply of this material available for widespread service at a relatively low price, instead of the very costly and extremely limited production of concentrated radium salts.

I have been successful in attaining both these ends, and have produced a radio-active preparation of moderate strength, which, for want of a better name, I have christened "Slow Radium."

I also wish to place on record the valuable help and services rendered by my friend Mr. Robert Young, of Four Oaks, during my research work, especially on the chemical side of this subject.

May I therefore ask the members of the medical profession to join me in verifying the efficiency

of "Slow-Radium" treatment, and so make good use of a new and reliable weapon for destroying unhealthy growth in or about the surface tissues of the body, without injuring the deeper-seated healthy cells?

"Slow-Radium," as perhaps the name suggests, acts slowly in contrast with the high-power Radium Salts.

The Applicators can be worn continuously for a considerable length of time, during which the healing process can be carefully watched by the Physician. There is no limit to the size of the Applicators, all of which act evenly upon the whole diseased area, however large the same may be.

This fact may be of importance in certain cases where it is desired to treat a diseased surface of such large dimensions that an Applicator of pure, concentrated Radium Salts could not be obtained.

CHAPTER II.

What Radio-Activity Means

I DO not intend to go very fully into the history of the discovery of the various new kinds of rays.* (Cathode Rays, Anode Rays, Leonard Rays, X-Rays, Becquerel Rays, α, β and γ Rays, and Radium Radiations), the origin and quality of which were epoch making and mysterious, but I shall rather try to record their dimensions, speeds and behaviour under peculiar conditions.

After the discovery of Radium in Paris in 1898, by Madame Curie—a lady gifted with a great scientific mind—one of our eminent physicists, Sir Joseph J. Thompson of Cambridge,† gave us the latest theory that the smallest, indivisible, penultimate part of an element is no longer the atom, but that every atom is composed of constellations of something much smaller than the atom—called "electrons"—possessed of a definite but extremely minute mass, and endowed with a prodigious kinetic energy.

*Light Visible and Invisible, by *Silvanus P. Thompson.*
Electrons or The Nature and Properties of Negative Electricity, by *Sir Oliver Lodge.*
Radio-active Substances and their Radiations, by *E. Rutherford.*
The Electron Theory, by *E. E. Fournier d'Albe.*
The Interpretation of Radium, by *Frederick Soddy.*
The Becquerel Rays and the Properties of Radium, by *Hon. R. J. Strutt.*
An Introduction to The Science of Radio-Activity, by *Charles W. Raffety.*

†The Corpuscular Theory of Matter by *J. J. Thomson.*
Electricity and Matter, by *J. J. Thomson.*

An atom can therefore best be imagined as a small universe in itself, in which the numerous stars and stellar groups are the various Electrons.

An atom is consequently very densely packed with Electrons, each moving unceasingly in orbits at a high velocity.

It is also surmised that the definite quantity of electrons in any atom determines the particular element to which the atom belongs.

This means then, that if one could add or subtract a certain number of millions of Electrons per atom, one element would be converted into another without more ado.

A working process to achieve this commutation has, however, not been found by the ever searching brain of man, but Nature—good natured mother to us—has shown us that it is actually possible, and in fact at the present time, several elements perform this marvellous phenomenon.

" Radio-Activity" is the name given to the voluntary and natural disintegration of the Atom. It means nothing else than the issue of the electrons from the womb of the atom. Take for instance, that of the element of Radium; its atom has become pregnant or " unstable " during the course of millions of years, and expels at the moment, uncountable millions of its constituent matter in the form of infinitely small particles which we have learnt to discriminate, measure, and observe by several methods, to which I will refer later.

Radium is, however, not by any means the only element of which the atoms are in the act of breaking up. There are a few others:—Thorium, Actinium, Zirconium, Uranium. All these shoot off Electrons at this period of the earth's existence.

It is possibly permissible, without rambling, to conclude, that all other elements will follow suit when nature has decreed that their span of life as self-contained units has reached its end. We know that only the elements of the heaviest atomic weight are at present doomed to disintegration, the lighter ones showing no signs yet of radio-activity.

Neither extreme heat, nor intense cold, can destroy radio-active atoms or interfere with their properties of issuing Electrons. The process of disintegration once having started, takes place uninterruptedly and lasts about 2,000 years with the Radium atom, and about 6,000 years with the Thorium atom. After their respective periods of "activity" which can be calculated, the atoms lose but little of their weight, and are merely gradually converted into atoms of a lower atomic weight; in the case of Radium for example, the atom is finally transformed by stages into the atom of lead. The atomic weight of Radium is 226 and that of lead 207.2.

Radium can consequently be described as a "temporary" element.

CHAPTER III.

The Products of Radio-Activity

RADIO-ACTIVE substances liberate several kinds of radiations:—

A heavier particle, called the Alpha (α) particle, or the "positive electron," and a lighter one called the Beta (β) particle, or the "negative electron." Both the α and the β particle is, however, always accompanied by a high velocity ray—called the Gamma (γ) Ray, which is very similar in action to the X-Ray of the Roentgen Tube.

There is also another by-product, a gas, called the "emanation."

In addition to these radiations, a constant production of "secondary" or "reflected" or "emergent" rays takes place.

The Alpha Particle.

The α particle is expelled at an initial speed of from 9,000 to 12,000 miles per second, and always carries a positive electric charge. Its volume is of atomic dimensions, about 1.4×10^{-16} c.cm., with a mass of 6.55×10^{-24}g.

The ratio of charge to mass for Alpha particles is:—

$$\frac{e}{m}=4.8\times10^{3}\ \text{EMU.}$$ (*C.G.S. electro-magnetic Units.*)

The number of α particles expelled per second from—

1 gram of radium $=3.4\times10^{10}$.

or 1 milligram of Radium expels 34 million α particles per second.

The number of α particles expelled from any radio-active substance, is in proportion to the amount of Radium contained therein.

The number of α particles emitted per square inch of Slow-Radium amounts to about 4,000 to 5,000 per second.

The Beta Particle.

The β particle travels at speeds varying from 50,000 to 180,000 miles per second, is the smallest particle of matter known, and of electronic dimensions with a mass of only 8.8×10^{-28}g.

It is extremely heavy for its size, and always carries a negative electrical charge of approximately 1.56×10^{-20} EMU.

The ratio of charge to mass:—

$$\frac{e}{m}=1.772\times10^{7}\ \text{EMU.}$$

The volume of a β particle is approximately 2.8×10^{-38} c.cm., which means that 3.56×10^{37} electrons would be contained in 1 c.cm., if such concentration were possible.

The weight of a " thimble full " of negative electricity of say, 1 c.cm., should therefore be approximately 31,400 tons.

The total loss of β particles from one milligramme of Radium C after a constant activity for 2,000 years, amounts to about 3.14×10^{18}, and that of α particles during the same period to 2.15×10^{18}, reducing the original number of electrons contained in the atom by only a very negligible quantity.

The number of β particles per square inch expelled by Slow-Radium is approximately the same as that of the α particles.

After 2,000 years, the radio-activity ceases and the " temporary " element of radium has been converted into the element of lead, still composed of fabulous millions of electrons in temporarily stable condition.

The Gamma Ray

The γ Ray is an ether motion, similar to a ray of light, and travelling at almost the same speed as light viz :—186,326 miles per second. It possesses no electrical charge and is a neutral ray.

It is produced by α or β particles colliding with an opaque object—the denser the latter is, and the greater the speed of the electron, the faster the resultant γ or X-Ray.

Heterogeneous Radiations

All Radium Radiations are of a heterogeneous kind, and in consequence each group exhibits

a large variety of performances when their respective rays travel through the medium immediately surrounding the radio-active substance from which they emerge.

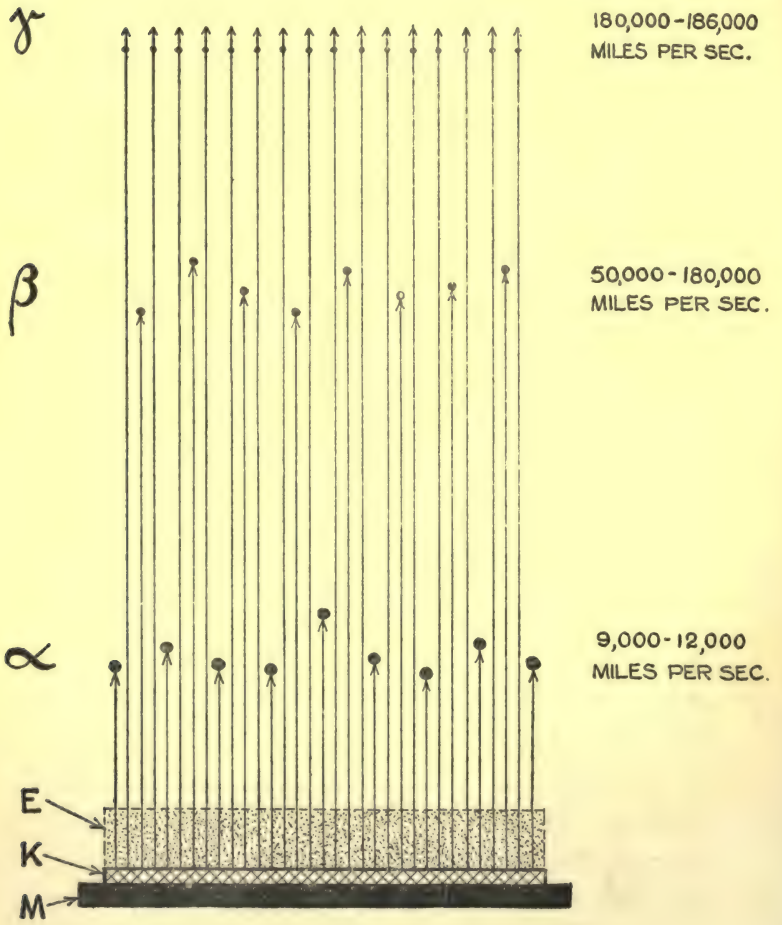


Fig. 1

Illustrating diagrammatically the products of radio-activity and the properties of the various radiations.

The α particles, owing to their relatively large mass and low velocity, penetrate only 1 to 3 inches into air, and after this excursion from the inside of the atom, they are arrested again by absorption, a process into which I will go more closely further on.

The lifetime of an α particle in air is, at most, about the one hundred millionth part of a second. If it strikes a body denser than air, it is absorbed much earlier, giving up its electrical charge at the point of collision, and at the same time causing one or more kinds of secondary radiation.

The distance which a β particle can travel in air after emergence from the disintegrating atom is limited to about eight feet, after which it is completely absorbed.

In aluminium for instance, or any denser material, the length of its path is considerably reduced, and absorption takes place much earlier.

The β particle has a penetrative power about one hundred times greater than the α particle. This is due to its being smaller in size, lighter in weight, and of greater initial velocity than the α particle.

α and β Radiations from the same radio-active substance are not always travelling at the same speed, consequently the effect of these various radiations differs greatly in that their absorption takes place at different times, and the resultant γ Rays are therefore also of a different quality.

The complexity of radium radiations requires very careful study, and I merely refer to these phenomena in this chapter *en passant.**

In strongly electrified or magnetically-saturated air, the α particle (being positively electric), yields and bends slightly — whereas the β particle (being negatively electric and very light) is deflected up to 180° out of its path.

*The Theory of Ionization of Gases by collision, by *John S. Townsend.*
Studies in Radio-Activity, by *W. H. Bragg.*
Radio-Active Substances and their Radiations, by *E. Rutherford.*

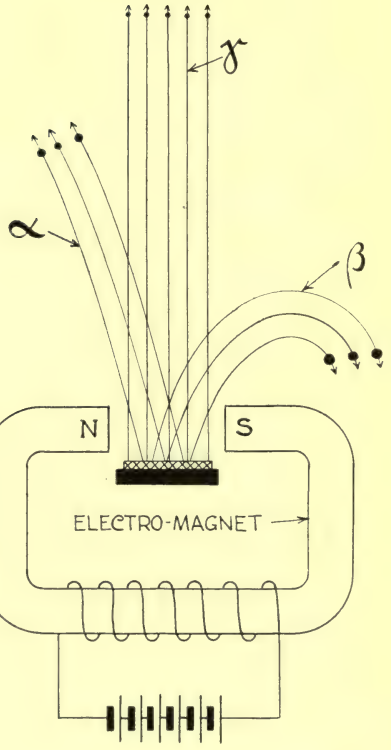


Fig. 2

Showing the influence of a powerful electro-magnetic force upon α, β and γ radiations.

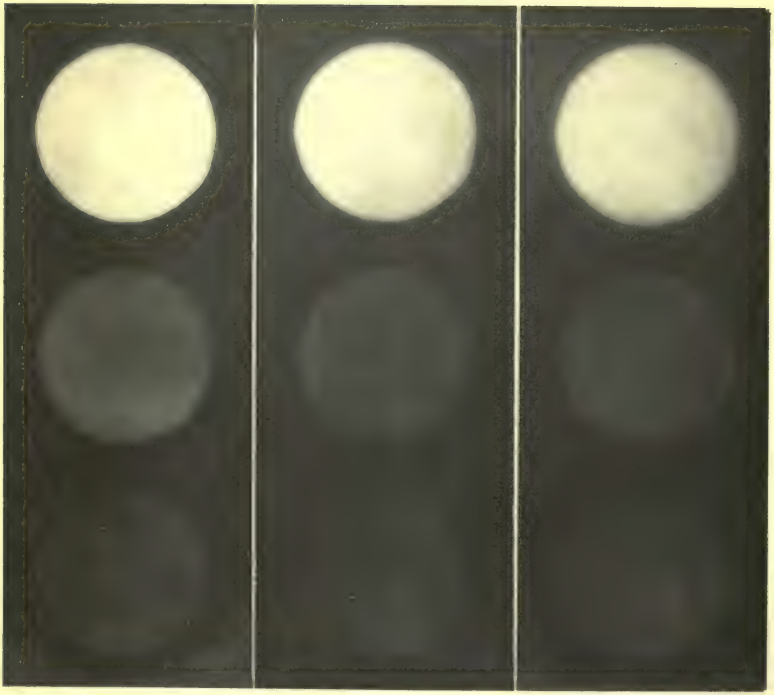


Fig 4

Film 1 Film 2 Film 3

Size of each X-Ray Film—8½in. × 6½in.
Time of irradiation, 72 hours.

CHAPTER IV.

How to trace Radio-Activity

α and β particles, also their accompanying γ Rays, emanating from radio-active sources, affect a photographic plate in a similar way to X-Rays.

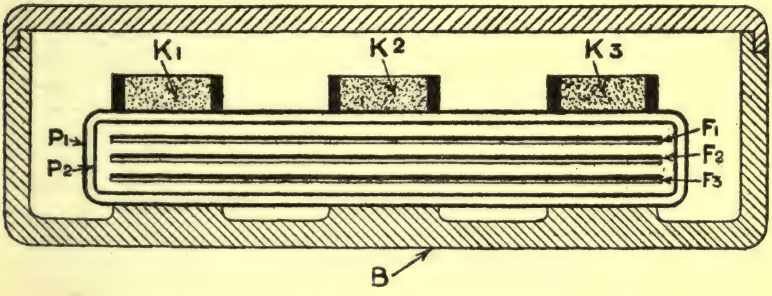


Fig. 3
K1—Slow Radium Powder full strength
K2— ,, ,, half ,,
K3— ,, ,, quarter ,,
P1—Red paper envelope.
P2—Black paper envelope.
F, F2, F3—3 X-Ray Films.
B—Light-tight box.

Figs. 3 & 4

If, for example, some radio-active powders, K1, K2 and K3, of different strengths are placed into lead rings on the top of two paper envelopes, P1 and P2, containing the three X-Ray films F1, F2 and F3 (with their sensitized surface upwards) and are thus left exposed to the

respective radiations from the active powders, it is found on developing the negatives that underneath each powder, the silver salts of all the three sensitized films have been " reduced " in the usual way—as if the films had been exposed to ordinary light.

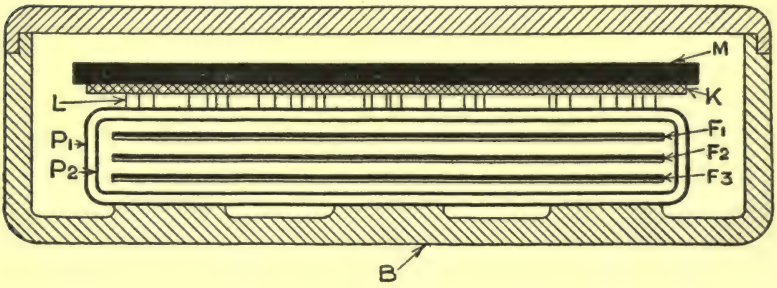


Fig. 5

M—Brass plate.
K—Slow Radium powder.
L—Layer of letters and figures, $\frac{1}{8}$in. high.
P1—First paper envelope.
P2—Second paper envelope.
F1, F2, F3—X-Ray films.
B—Light-tight box.

Figs. 5 & 6

Six metal letters, K R A M E R, and two metal figures 7 and 2, were placed on the top of two paper envelopes, P1 and P2, enclosing three X-Ray films F1, F2 and F3. Immediately above the metal letters L, which were about $\frac{1}{8}$in. high, was placed a brass plate M, the underside of which had been covered with a layer of Slow Radium powder. After exposing the films for 72 hours in the dark, in a box B, they were developed, and the result is shown in Fig. 6.

Fig. 6
Size of X-Ray Films, 8½in. × 6½in.
Time of irradiation, 72 hours.

Fig. 8
Size of X-Ray Film, 8½in. × 6½in.
Time of irradiation, 500 hours.

The α particles did not penetrate the paper envelopes, but the β particles and the γ Rays penetrated them and left deep shadows of the metal letters and figures on the three films.

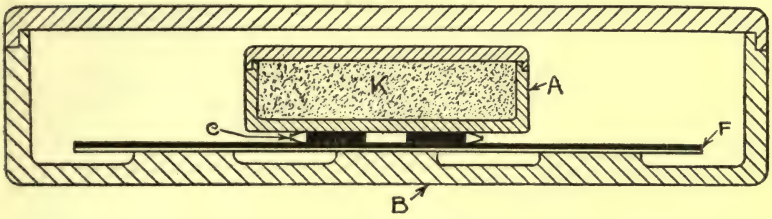


Fig. 7
A —Aluminium box, $\frac{1}{8}$in. thick.
K—Slow Radium powder.
C —Brass cog wheel.
F —X-Ray film.
B —Light-tight box.

Figs. 7 & 8

A quantity of Slow Radium powder was enclosed in an aluminium box A, the walls of which were $\frac{1}{8}$in. thick. Underneath this box was placed a brass cog wheel C, the latter resting upon an X-Ray film F. After 500 hours irradiation the film was developed, and the result is shown in Fig. 8.

Owing to the great thickness of the aluminium box A, possibly only the γ Rays penetrated, the β particles (at least the softer ones) having been absorbed by the $\frac{1}{8}$in. thick aluminium bottom of box.

Whilst X-Rays would produce similar photographic results in a much shorter time, concentrated (pure) Radium Salts would not be

suitable to take photographs of such large dimensions, as a Radium Applicator is only of a very small size, owing to the scarcity and high cost of Radium.

With "Slow Radium," which is not so scarce and much less expensive, metal plates of large area can be covered and photographs up to several hundred square inches can be produced.

Fig. 9

A "Slow Radium" Applicator was placed over an X-Ray film and exposed for 19 hours in a box impervious to light with the result shown in Fig. 9 (Frontispiece).

Effect on Fluorescent Screens

Radiations from radium preparations can also be traced by the illuminating effect on fluorescent screens of various kinds (zinc-sulphide, or platino potassium or barium cyanide), but as this method does not lend itself to the observations required for the object of this book, I will not go into details.

Sir William Crooke's Spinthariscope is an excellent little instrument for showing the scintillations from the radiations of Radium salts. Whenever a particle strikes the zinc-sulphide disc, a small spark appears at the point of collision. This is most likely due to the heat generated by the impact of the high velocity particle with a particle of similar dimensions on the surface of the disc. The

particle is not itself luminous, but causes the zinc-sulphide molecule to be illuminated and therefore observed.

Tracing and measuring Radium Radiations by Ionization

The electrical properties of the α and β particles expelled from radio-active substances, have been made use of in devising an electrical method for testing and comparing the relative strength of radiations.

All radium radiations have, what is called, ionizing powers, which means that the air immediately surrounding the radio-active substance becomes a kind of conductor of electricity, and is, as such, capable of carrying a very minute current from one metal plate on which the radio-active substance is placed, to another about one inch above it. For instance, the more α particles thrown out, the greater the conductivity of the ionized layer of air between the two plates.

This is by no means quite so simple as it would appear, and it is difficult to imagine how a layer of air can be made a conductor of electricity. As, however, the method of measuring the strength of radium radiations is of great importance, I would like to explain more in detail what happens between the two metal plates when an electric current is made to pass. When an α or β particle or even a γ or X-Ray collides with a molecule of air, it splits up the

latter into its constituents, releasing from it positive and negative ions. As it has been shown in figure 2, page 13, positive and negative particles, answer electro-magnetic forces, and can be deviated from their course, it is also easily understood that these particles answer in all other respects to the laws of influence of one electric charge upon another. If, therefore, the metal plate which carries the radio-active material is connected to an electric source, the electric field immediately surrounding the metal plate so connected, acts upon the positive and negative ions released from the air molecules in such a way, that it attracts or repels them in accordance with the nature of their respective charges.

If the charge upon the metal plate is positive, it repels the positive ions and sends them upwards, at the same time attracting the negative ions downwards. The result is that a stream of positively charged ions is carried from the lower metal plate to the one above, and the latter in turn will receive a positive charge. There are, however, two other important features to be considered in this process, and these are rather intricate; the one deals with the phenomenon which is called " saturation current," the other the " re-combination process " of the released ions of opposite potentials with those of another, thus forming fresh molecules of air. Rutherford, in his admirable work on " Radio-active Substances and their Radiations " and Townsend

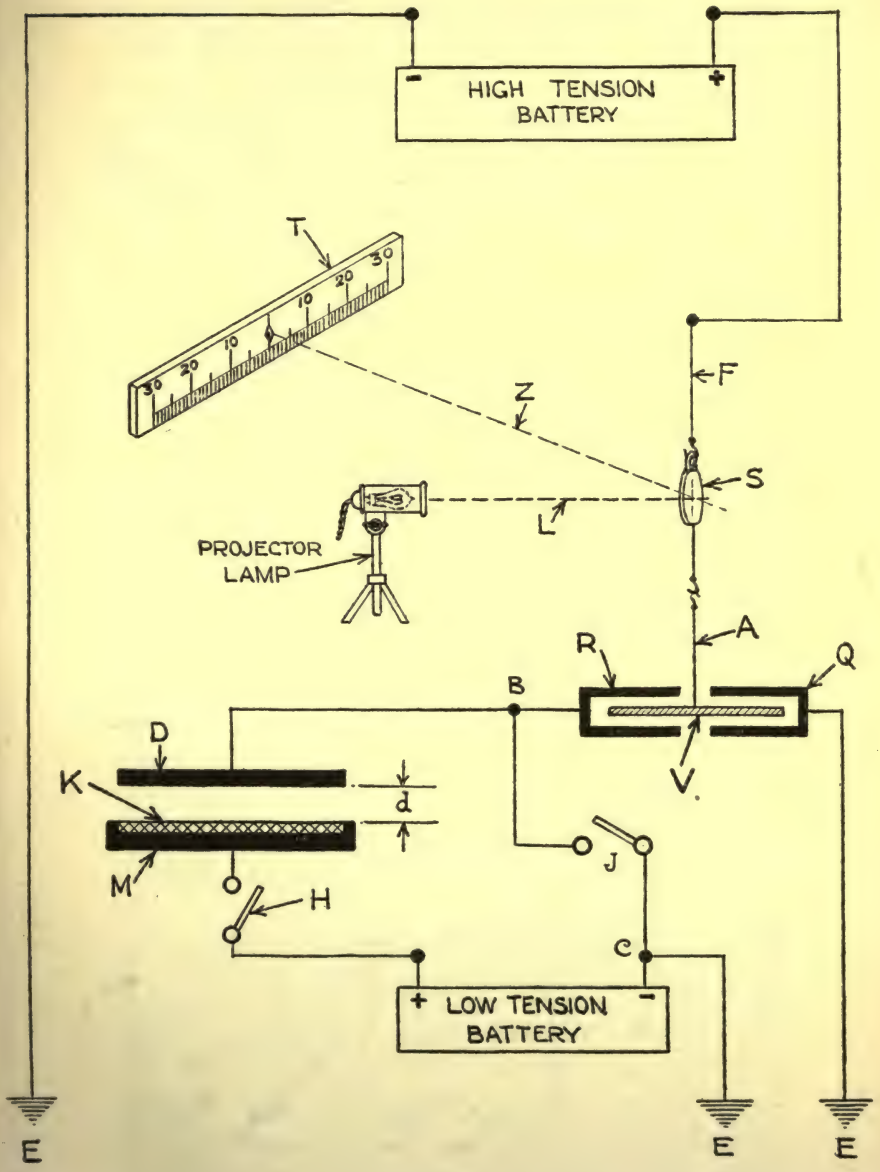


Fig. 10

Diagram of an ionization apparatus for measuring Alpha radiations.

in his excellent treatise on "The Theory of Ionization of Gases by Collision," deal very fully with these subjects.

Let it in the meantime suffice to say, that the method of measuring the presence and strength of electrons in radio-active substances by means of "ionization" is most expeditious and accurate.

Fig. 10

The following is a description of an apparatus which is frequently used for this purpose.

A radio-active powder K, is placed upon a metal dish M, above which is suspended a metal plate D, electrically connected to two opposite quadrants R of a very sensitive electrometer. The other two quadrants Q, are connected to "earth" E. Inside the four quadrants an aluminium vane V is suspended from a very fine tungsten filament F. Between F and V is a small silver mirror fixed to a thin aluminium wire. The filament F is connected to the positive pole of a high-tension battery of about 200 to 300 volts, the negative pole of which is earthed.

The metal dish M is electrically connected to the positive pole of a low tension battery, the negative pole of which is earthed. There is a switch H between the metal dish and the low tension battery, and another, highly insulated, switch J is inserted between B and C. Before any reading is taken, switch J is kept closed, but on opening this switch, a positive

charge gradually accumulates on the suspended metal plate D, and the magnitude of this charge depends—

1. On the amount of α electrons present in the radio-active material K.
2. The voltage of excitation on metal dish M.*
3. The distance d between M and D. (The greater the distance the greater the charge upon D).†
4. The time during which switch J is open.

The effect of the accumulated positive charge upon plate D is observed by a ray of light thrown by mirror S from a projector lamp and reflected by a beam of light Z upon scale T.

Owing to the positive potential of the charge received by the quadrants R, and the negative charge upon the quadrants Q, the aluminium vane V is turned slowly, with the result that the beam of light Z travels from the zero position on the scale until it reaches say division "20."

The whole apparatus can be so adjusted that, for instance, with a radio-active powder of moderate strength, it will take 10 seconds for Z to travel from 0—20.

*There is a limit to the increase of the electric pressure, which is reached when the "Saturation Current" starts making its appearance.

†This seems at first sight paradoxical, but the "Ohmic Law" does not hold good in this case.

It is more important that the volume of air between M & D should be large, as more ions are produced. There is, however, a limit to the maximum distance d, and if this becomes too large, the charge upon D appears to be reduced, as then the radiations get absorbed, their journey in air being limited.

Distance d can therefore be compared to the "Focal distance" of a lens.

If then, a feebly radio-active powder is put on metal dish M, it will take say 80 seconds until Z reaches 20 divisions on the scale, or alternatively if a stronger radio-active powder is put on dish M, Z will travel from zero to 20 in perhaps $4\frac{1}{2}$ seconds.

The time is measured by a stop watch from the moment when switch J is opened until the beam of light Z has reached division 20 on scale.

By this ionization method, the quality and strength of radium radiations are quickly and accurately determined.

CHAPTER V.

Penetrative Powers of Radium Radiations

IT is truly remarkable how a particle of matter can be thrust through opaque and apparently solid substances and emerge with more or less unabated vigour for its further onward travel through space !

The reason for this is, that materials, even of great density such as copper or lead, are not really homogeneous, and if these so-called dense metals were seen under a " super-microscope," we would find them " honeycombed " or sponge-like fabrics, with probably ether in their combs.

This accounts for the fact that a particle of matter of very small mass, but moving at prodigious speed, can penetrate dense substances.*

The electrons pierce the thin walls of each comb or cell like a machine gun bullet pierces a sheet of paper.

Each time this takes place, however, the little electron bullet loses some of its velocity, and as there are many thousands of combs or cells in its path, the electron is slowed down until it

*For the sake of the point I wish to make, I would like to let this comparison stand, although it would be more correct to regard the structures of all materials—organic and inorganic—as being composed of " electrons."

finally comes to rest, and is stopped or what is called "absorbed." If the thickness of the substance into which it is thrust is not too great, it will emerge once more into space, but at a very much reduced speed, and after a little while it is "spent" by absorption in air.

It is of paramount importance to recognise the penetrative powers of the various radiations before we can understand their actions upon substances such as the tissues in radium treatment, at any rate as far as the physical effect is concerned and quite apart from the chemical or electrical actions resultant from any collision of the radiations, with the normal or pathological cells.

For this purpose, I propose to describe first a series of experiments, which will demonstrate the various penetrative powers of α and β electrons and the γ Rays from Slow Radium.

The penetrative powers of radium radiations, depend upon the following factors:—

1. The dimension and mass of the radiating particle.
2. The actual speed of same at the various points of collision with each individual cell.
3. The density and thickness of the medium between the radio-active material, and the substance to be pierced.
4. The density of the object under test.

5. The amount of electrical charge upon the α particle or the β electron.
6. The chemical condition of the substance.
7. The electrical condition of the substance.

Fig. 11 shows the effect of the α, β and γ radiations on meeting a dense substance, after having travelled through a short air space between the radio-active material and the substance. The illustration shows an α particle just leaving the Slow-Radium layer K, and at that point it possesses its greatest speed which, however, will be decreased in proportion to the depth of the air space between the Slow-Radium and the substance.

Every millimetre of air thickness decreases the speed of an α particle, not in direct proportion, but by about one thirtieth to one twentieth of its original speed, and therefore by the time the α particle reaches the outer skin of the substance, it is already fatigued. This fatigue however, does not mean that the α particle has done no work for the loss of a portion of its energy, as it has broken up some millions of air molecules, and released some of their constituents, which in turn act upon the outer skin of the substance. I shall refer to this point again in the next chapter.

After the α particle has pierced the first layer of the substance, it will be absorbed.

The depth of penetration depends entirely upon the density of the substance, and should

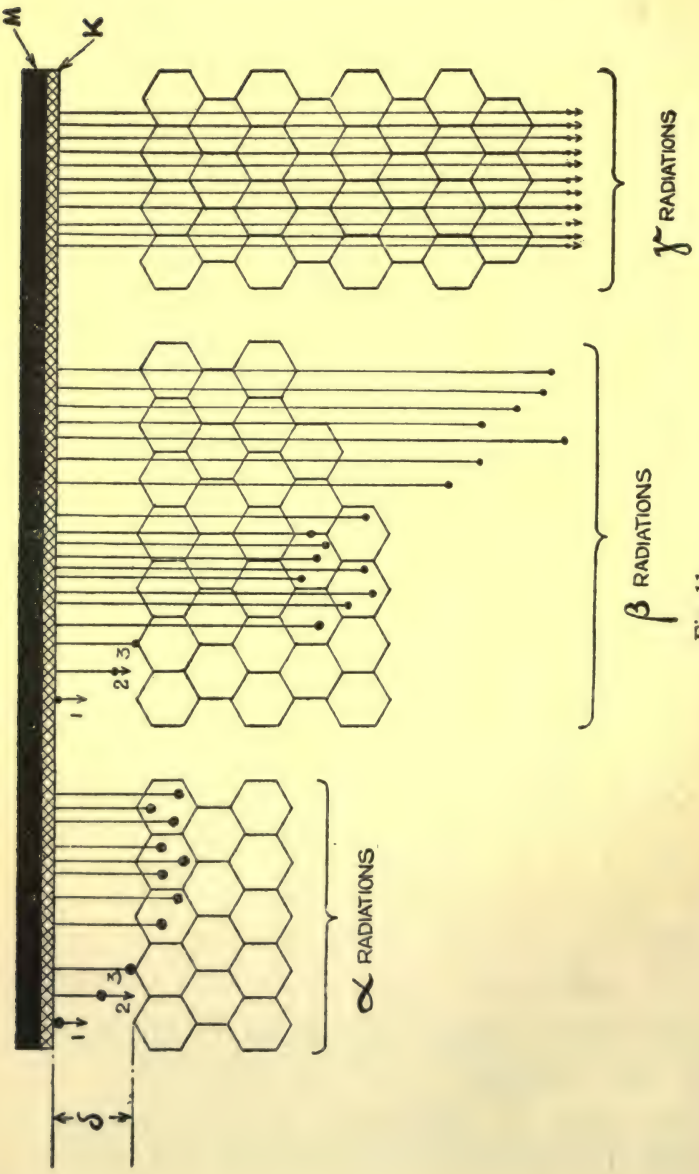


Fig. 11

Diagram showing relative penetration of α, β and γ radiations.

this be human skin, which has a lower density than muscular tissue, the Alpha particle will only penetrate about one-tenth millimetre.

The β particles, which are the negative electrons, owing to their small mass and greater initial speed, penetrate very much deeper into tissues before they are absorbed.

In air, β particles can be traced from about 10ft. up to 30ft. in length before they are entirely absorbed. This wide range is due to the many different kinds of β radiations which are shed off from radium or radio-active substances.

The depth of penetration of the β particle again depends on the density of the substance they strike.

In the case of the tissues, Slow-Radium β particles penetrate from about $\frac{1}{4}$in. to $\frac{1}{2}$in. before they are absorbed.

Fig. 11 shows how some of the β radiations have penetrated into the substance, piercing a number of cells and being stopped at varying depths, also how some β particles have passed through the substance where the depth was not great enough to absorb them, and have travelled a further distance outside the object before they have been stopped in air.

The γ Ray like the X-Ray, is possessed of still greater penetrative power. It can be

compared to a more or less disembodied mass moving almost at the speed of light. It is not usually considered to be a particle at all, but is mostly referred to as a Ray. The great difference however, between a ray of light which travels at 186,330 miles per second and a γ Ray or X-Ray, which travels at about the same speed, is that the latter can penetrate opaque matter (as is shown by radio photography), whereas an ordinary ray of light cannot reduce the silver salts on a photographic plate, if the latter is enclosed, even in one layer of black paper. The difference of penetrative power between an ordinary ray of light and a γ Ray, X-Ray or Ultra Violet Ray—although they are all travelling at the same speed—is therefore apparent, and it raises the controversy whether the γ Ray is really void of mass altogether, and is a pure ether motion or not?

γ Rays travel in air about a quarter to half a mile before complete absorption takes place. They possess great ionizing powers, and when highly concentrated are dangerous rays to meet, owing to the destruction they leave in their wake.

In tissue, they travel from 2—3 feet deep; in aluminium, they are practically stopped by a thickness of 8—15 inches, and in lead, they are absorbed in about 4in. minimum to 8in. maximum thickness.

γ Radiations are always in evidence after the α and β particles have been absorbed.

It is impossible to screen off γ Rays without, at the same time, absorbing the α and β radiations.

On the other hand, the α and β particles are far more valuable for the treatment of pathological cells, and in the X-Ray treatment you have neither, but the complex X-Ray only, the consideration of which is outside the scope of this book.

The amount of γ Rays present in Slow-Radium is very limited as compared with those in Concentrated Radium.

Possibly therein lies the whole crux of Slow-Radium Treatment versus Concentrated Radium and X-Ray Treatment.

This important point is again dealt with more fully in chapter VII.

CHAPTER VI.

The Effect of Penetrations from Slow Radium

THE effect of light when falling upon the sensitised layer of a photographic plate or film, is a spontaneous reduction of the silver salts, and according to the strength of the light and the time during which the plate is exposed to the light, the reduction is more or less complete. In fact, a photographic film is one of the most sensitive instruments for recording the strength of the light to which it is exposed, and the time of the exposure, or in other words, "the total quantity of light beams absorbed by the film." The various shades produced on photographic prints from negatives often indicate to the trained eye the kind of light in which the photograph was taken and also the time of the exposure.

When in 1895, the Bavarian Professor Wilhelm Konrad Roentgen discovered, whilst carrying out tests with the then new Lenard Rays, that a photographic plate, if placed in the wake of those Rays, was completely "fogged" after development, it was thereby made manifest for the first time that light, other than ordinary sunlight, could penetrate opaque matter and still influence a photographic plate.

At first this kind of light was called Roentgen Light, and later on when Roentgen perfected his special vacuum tubes, he gave that light the name of " X-Rays." Except during recent years, when they have also been experimented with for therapeutics, the X-Rays were principally employed for photographing the bones and certain internal organs, such as the heart, the lungs, etc., as X-Rays very easily penetrate tissues, and are only more or less absorbed by the bones and denser parts of our bodies.

Again, the photographic plate has proved in this work a wonderful instrument giving with the aid of X-Rays most sensitive and true pictures of objects which no ordinary kind of light has power enough to penetrate, and still affect a photographic negative, disclosing to our eyes objects otherwise invisible to us.

In X-Ray photography we have to consider several essential conditions, viz:—

1st. The intensity of the X-Rays penetrating the opaque substances.

2nd. The density of the substance.

3rd. The time of their exposure (irradiation).

The intensity of the X-Rays depends on their various speeds and they are therefore classified into soft, medium and hard Rays, the hardest Rays being those possessing the greatest velocity.

The photographic process discloses the various densities of the substances which X-Rays can either totally or partially penetrate.

The longer an X-Ray film is exposed to either light or X-Rays of a given intensity, the more silver salt particles are reduced, and the deeper the Rays penetrate into the layer of sensitised film. The combined effect of the " intensity " of the X-Rays and the time of irradiation is really equivalent to the quantity of silver salts reduced, and consequently is a direct indication of the total quantity of X-Rays or " Dose " required to cause such an effect. It is important to realize this when studying the effect of penetration of irradiations from other than ordinary light rays—such as those which are the subject of this book.

In 1896, immediately after the scientific world received information of the wonders of the X-Ray, Professor Henri Becquerel of Paris, also Professor Silvanus P. Thompson of London independently and almost simultaneously discovered another kind of invisible radiations emitted by uranium and its salts.

Once more the photographic plate revealed their presence and properties.

The same must be said of the Radium salts, which became known a year later than the Becquerel Rays.

The radiations from Radium salts and from those providing Becquerel Rays are of the same nature, the former however are more intense in their action being very highly concentrated.

Dealing now with the effect of radiations from radio-active matter, viz., the α, β, and γ radiations, we not only have to consider the two

items essential in ordinary light photography, nor the three points in X-Ray photography, but a far more complicated process, subject to the following conditions:—

1. The properties of the α particles.
2. The properties of the β particles.
3. The properties of the γ Rays.
4. The properties of secondary radiations, often called "emergent" or "reflected" rays.
5. The time of irradiation.
6. The distance from the source of the radiations, and the photographic film; for instance, the thickness of a layer of air, the thickness of the paper in which an X-Ray plate is wrapped, or any other medium interposed between the radium salt and the photographic film.
7. The various densities of these media.
8. The electrical conditions, if such prevail, of the media to be radiated.
9. The physiological, pathological and chemical conditions of the substances.

From this list of essential conditions on which depend the effects of the irradiation of a substance exposed between the layer of radium salts and the layer of sensitised film, you will see that it is by no means a simple process. The exposure therefore of any substance such as human tissues to radium radiations requires a very careful analysis. Such an analysis is best

revealed to us by the photographic process with X-Ray films or plates.

I therefore, have thought it advisable to publish and describe a number of photographs, which were obtained by passing Radium and Slow Radium radiations through various natural and artificial substances, as well as muscular tissues.

The Effect of the Alpha Particle

Fig. 12.

A one-inch diameter metal disc was coated with Slow Radium, and placed within $\frac{1}{16}$ of an inch over an X-Ray plate for three hours, with the result shown in figure 12, see dark grey impression, marked I. The Applicator was then shifted into position II for six hours and the colour of the impression was then much lighter. It was then moved into positions III, IV and V, leaving it exposed for nine, twelve and fifteen hours respectively. The impression of picture No. V, after fifteen hours' irradiation, resulted in an almost complete reduction of the silver salts, showing a white disc in the illustration.

In these five cases, all the radiations, α, β and γ were active.

I then cut off the α Rays by means of a $\frac{1}{4}$ millimetre thick aluminium sheet and put the Applicator with the aluminium sheet underneath, into position VI for fifteen hours, resulting in a light grey impression which in

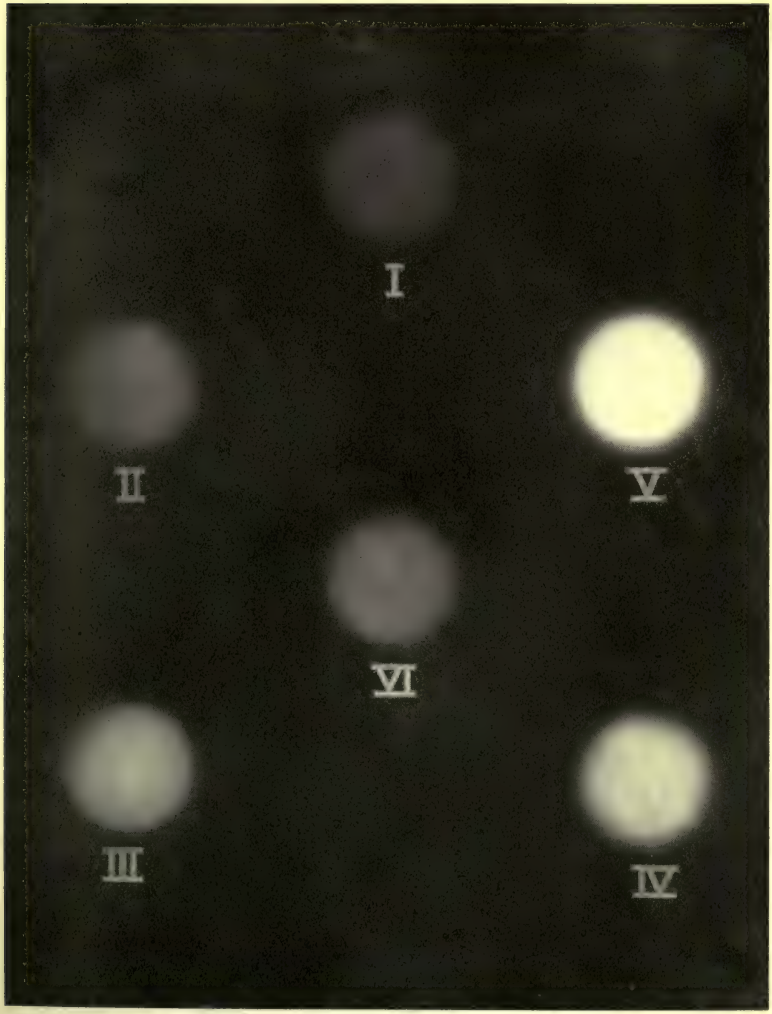


Fig. 12

Size of X-Ray Plate, 8½in. ×6½in.
Time of irradiation, 3—15 hours.

intensity compares with the impression made in case II.

When taking the impression VI, the β and γ Rays only were active.

It is therefore evident that the effect after excluding the α particles is $2\frac{1}{2}$ to 3 times weaker than that including all the radiations present.

The α particle is however, of great therapeutic value, having a large mass and being therefore more destructive in comparison with the very small β particle and the highly penetrative γ Ray. When using pure radium salts, the α particles are usually prevented from acting on the diseased skin by several layers of varnish or gutta-percha wrapping, covering the surface of the radium salt. With all Slow Radium Applicators, the α Ray is always active, unless it is purposely cut out by an aluminium or other screen.

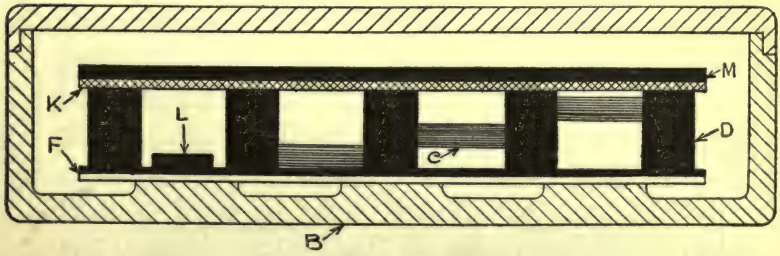


Fig. 13

Fig. 13

A similar effect is obtained by stopping the α particles with a piece of chamois leather, permitting only the β and γ radiations to reach the sensitised layer of the X-Ray film. I placed three strips of chamois leather, marked

C, spaced by copper distance pieces D, between a metal plate covered with Slow-Radium K, and a photographic X-Ray film. The chamois leather strips were placed at different heights, the first one being next to the Slow Radium layer, the second strip in the middle between the Slow-Radium and the photographic film, and the third chamois leather strip was placed next to the photographic film. The fourth opening was left uncovered, permitting the α particles to freely reach the film direct. L denotes two lead figures 4 and 8, which were put on the plate in the centre of the fourth opening. The result is shown in Fig. 14.

By close observation, you will find that the image of the first strip, nearest to the Slow Radium, is slightly brighter than the second and third strips, but all three are considerably darker than the image of the fourth strip with the figure 48 in the centre. The reason for this is that the α particles have been stopped by the chamois leather and the β particles and γ Rays only got through to the photographic film. In the case of the first strip, the β particles having been obstructed close to their source, have not been slowed down so much as in the case of the second and third strips, when the β particles were already somewhat fatigued by their passage through the layer of air between the Slow Radium and the chamois leather, and therefore had not the power to reduce the silver salts quite as much as in the first place.

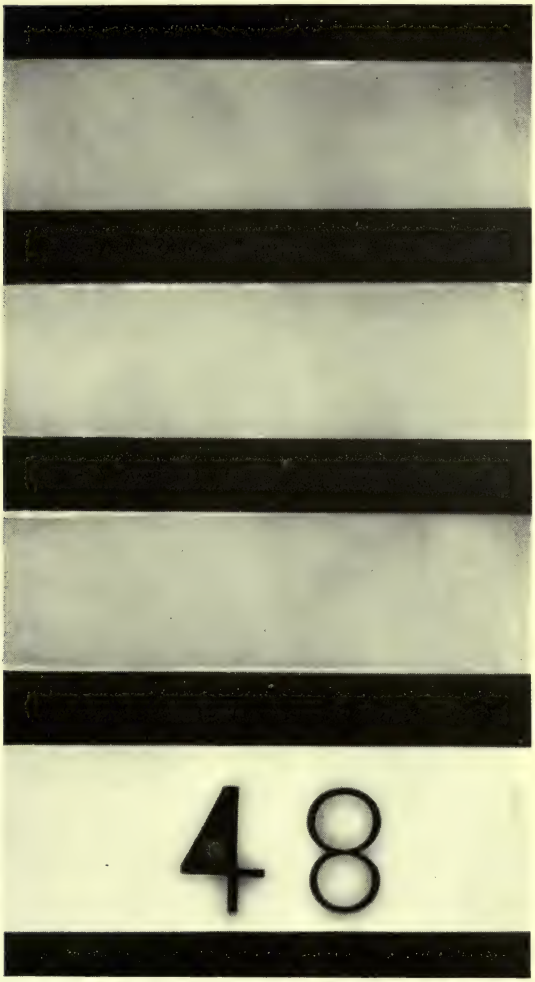


Fig. 14

Size of X-Ray Plate, 8½in. × 6½in.
Time of irradiation, 48 hours.

Fig. 15

Size of X-Ray Plate, 8½in. × 6½in.
Time of irradiation, 72 hours.

In order to prove this more clearly, I have taken another photograph substituting the chamois leather strips by celluloid strips of $\frac{1}{16}$ of an inch thickness and irradiated, instead of 48 hours, for 72 hours. The positions of the celluloid strips were arranged similarly to those shown in Fig. 13, but they were a little smaller in width, leaving a narrow air space on each side near the copper distance pieces for the α particles to get through. The result is shown in Fig. 15, and you will observe more distinctly that the intensity of the penetration through the first celluloid strip was stronger than those of the other two. You will also observe that in the illustration the top strip hardly shows the effect of the narrow air gap above and below the strip through which the α Rays had passed, whilst in the second and third impressions you notice a distinct white line showing a difference in colour. In the fourth strip, where the letters 72 appear, the α Rays were acting direct upon the X-Ray film. The total air gap between the Slow-Radium powder and the X-Ray film throughout these tests, was about $\frac{1}{4}$ inch.

The Effect of Beta and Gamma Radiations after their passage through Solid Substances

Figs. 16 & 17.

An X-Ray film F was covered by a brass plate D, with six openings, each of 2in. diameter. Over each of these openings, discs of different materials of different thickness

were placed. On top of these discs at a distance of $\frac{5}{16}$ inch from the X-Ray film, a metal plate M, with a Slow-Radium layer K, was supported and the whole was then enclosed in a light-tight box B.

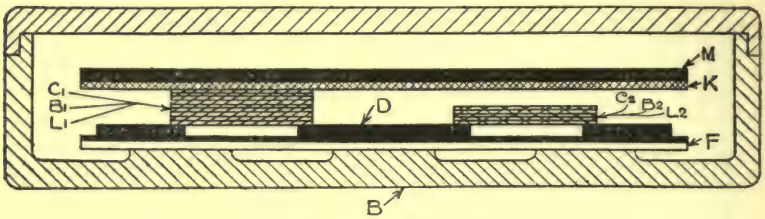


Fig. 16

The substances under observation were:—

C1. $\frac{1}{4}$in. thick chamois leather disc.
C2. $\frac{1}{8}$in. thick chamois leather disc.
B1. $\frac{1}{4}$in. thick compressed black paper disc.
B2. $\frac{1}{8}$in. thick compressed black paper disc.
L1. $\frac{1}{4}$in. thick celluloid disc.
L2. $\frac{1}{8}$in. thick celluloid disc.

After irradiating the discs for 238 hours, the results were as shown in Fig. 17. All α Rays were eliminated, and the β and γ Radiations only were able to pass. This proves that chamois leather permits of an easier passage of these radiations than black paper or celluloid, but as black paper and celluloid are very nearly of the same density the shades of the prints are closely alike, with the exception of the thick celluloid disc on the left-hand side bottom corner (Fig. 17), which is somewhat darker than the black paper disc

$\frac{1}{4}$in. Discs. $\frac{1}{8}$in. Discs.

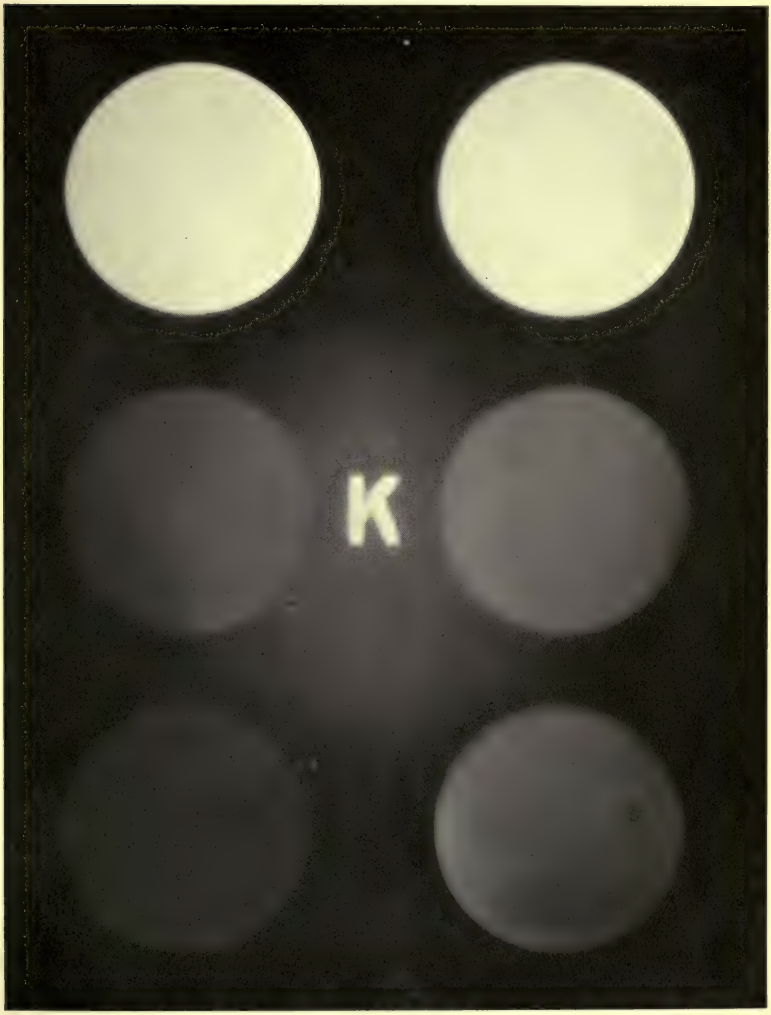


Fig. 17

Size of X-Ray Plate, $8\frac{1}{2}$in. $\times 6\frac{1}{2}$in.
Time of irradiation, 238 hours.

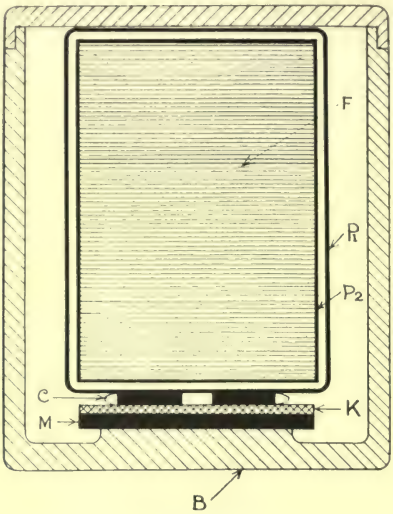


Fig. 18

F—Packet of 100 Celluloid X-Ray Films.
M—Metal Plate.
K—Slow Radium Layer.
C—Cog Wheel.
P_1 & P_2—Black Paper.
B—Light-tight Box.

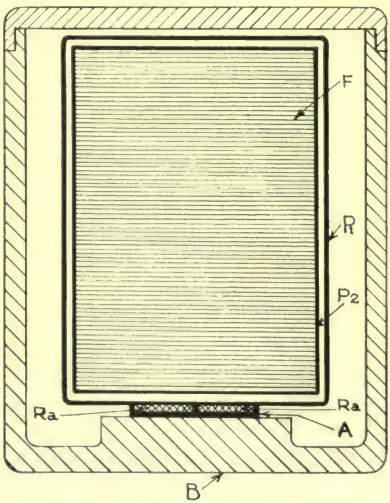


Fig. 19

A—Radium Bromide Applicator.
Ra—Radium Bromide, 1cm.×2cm.
F—Packet of 100 X-Ray Films.
B—Light-tight Box.

immediately above it. This is due, I think, to the glue with which the various celluloid discs were stuck together. The shade of the right-hand side bottom disc ($\frac{1}{8}$in. celluloid), and that immediately above it ($\frac{1}{8}$in. thick compressed black paper) are practically alike. The "fogging" round the centre of the plate is due to the α Rays having passed through the letter K, which was cut out from the brass plate upon which the various discs rested, and through this opening the α particles passed in large quantities.

As I have already pointed out, the density of the muscular tissue, that of flesh or meat, and those of celluloid and black fibre, are about the same, and consequently α, β and γ radiations in these substances are absorbed in approximately the same degree.

Fig. 18

In order to investigate the effect of a long exposure of β and γ radiations upon a considerable depth of material similar in density to tissue and flesh or meat, I decided on the following tests. A packet of 100 X-Ray celluloid films enclosed in two layers of black paper wrappers were put in a light-tight box B. At the bottom of the packet of films, a small gear wheel C rested upon a metal plate M, with a layer of Slow-Radium facing the packet. After an irradiation of 500 hours, each film was developed, and the result is shown in Fig. 20. It was found that the β and γ radiations

penetrated through the two layers of paper plus $\frac{3}{16}$in. of celluloid films. Each film was .01in. thick, and 18 films were affected as shown in Fig. 20. The first 12 films, which is equivalent to $\frac{1}{8}$in. penetration (including envelopes) show very definite effects.

Fig. 19

In order to realize the importance of this test, I decided to publish three similar results obtained with pure Radium Bromide Applicators, as follows:—

The Radium Bromide Applicator was placed under a packet of 100 X-Ray films, which were wrapped in double-paper envelopes and enclosed in a light-tight box. (See fig. 19).

The first packet was irradiated for $\frac{1}{2}$ hour, the second for 1 hour, and the third for 2 hours. Each film was then developed and the results are shown in Figs. 21, 22 and 23.

As each film was again .01 inch thick, and 35, 44 and 60 films respectively were affected, this represents a depth of penetration of the β and γ Radiations of $\frac{3}{8}$in., $\frac{1}{2}$in., and $\frac{5}{8}$in. for the three different tests.

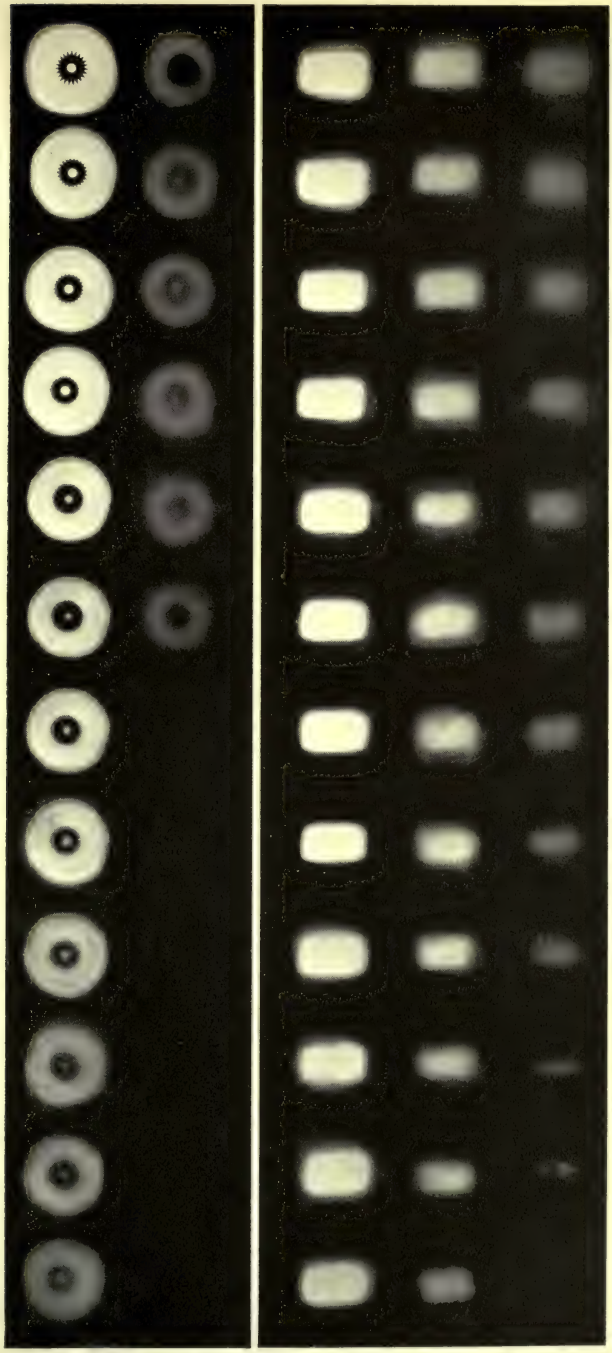


Fig. 20 Slow Radium.
Irradiation, 500 hours.
18 films affected.

Fig. 21 Radium Bromide.
Irradiation, ½ hour.
35 films affected.

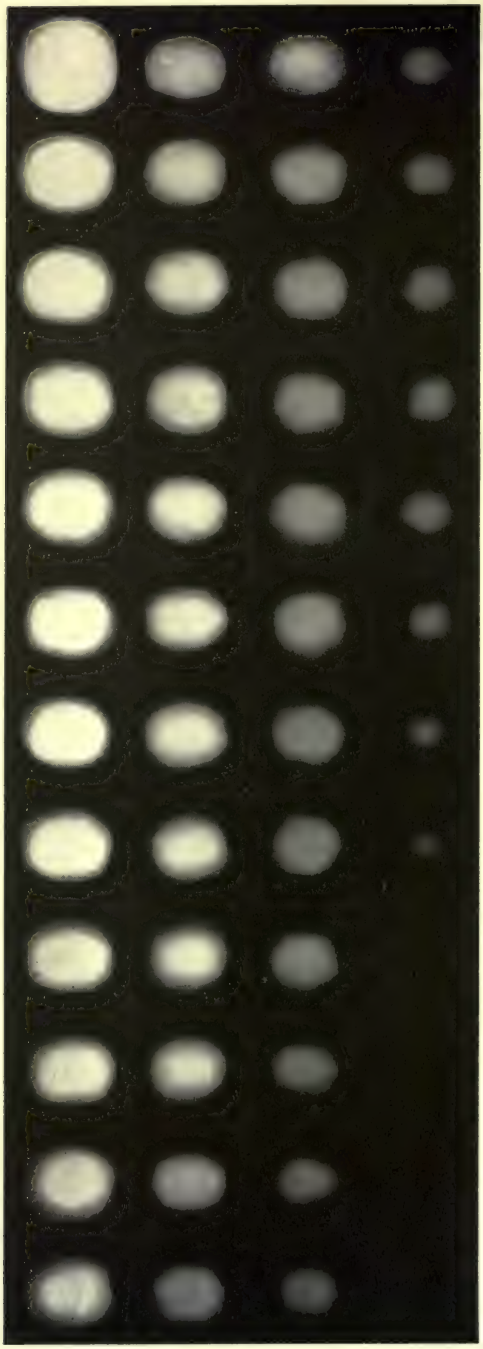


Fig. 22 Radium Bromide.
Irradiation, 1 hour. 44 films affected.

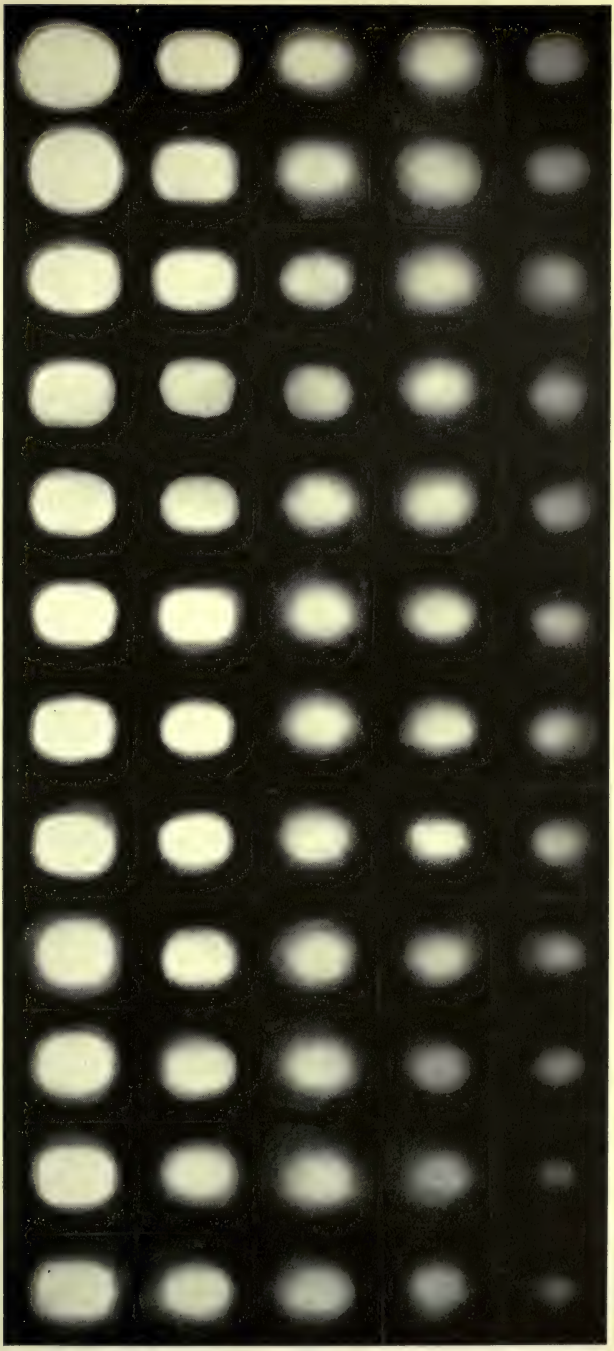


Fig. 23 Radium Bromide.
Irradiation, 2 hours. 60 films affected.

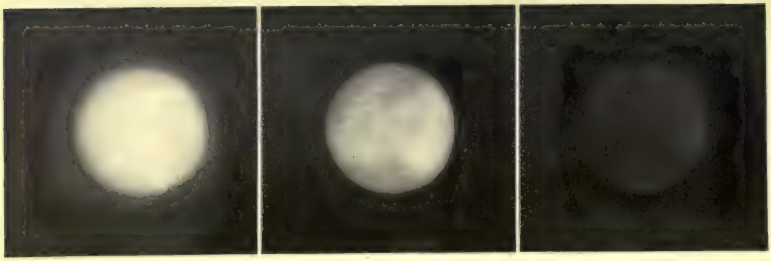


Fig. 24 Fig. 25 Fig. 26
Thickness of Meat $\frac{1}{16}$in. $\frac{1}{8}$in. $\frac{1}{4}$in.
Irradiation: 500 hours, with Slow-Radium.

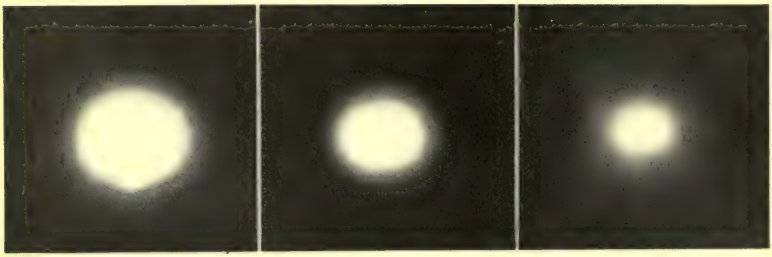


Fig. 27 Fig. 28 Fig. 29
Thickness of Meat $\frac{1}{8}$in. $\frac{1}{4}$in. $\frac{1}{2}$in.
Irradiation: $\frac{1}{2}$ hour, with pure Radium Bromide.

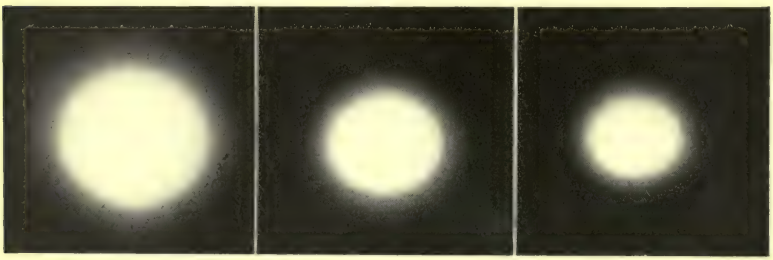


Fig. 30 Fig. 31 Fig. 32
Thickness of Meat $\frac{1}{8}$in. $\frac{1}{4}$in. $\frac{1}{2}$in.
Irradiation: 1 hour, with pure Radium Bromide.

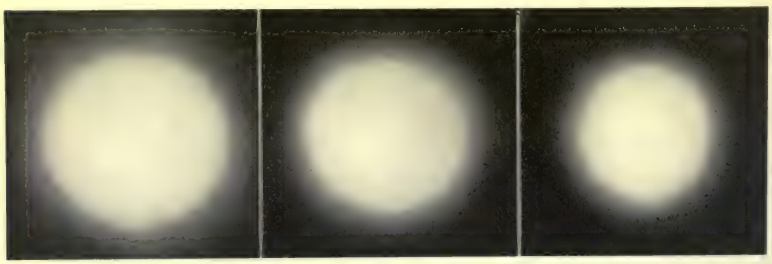


Fig. 33 Fig. 34 Fig. 35
Thickness of Meat $\frac{1}{8}$in. $\frac{1}{4}$in. $\frac{1}{2}$in.
Irradiation: 2 hours, with pure Radium Bromide.
NOTE.—The above reproductions are approximately $\frac{1}{4}$ full size.

Irradiation of Pieces of Meat

Figs. 24—35

Certain kinds of celluloids possess very nearly the same density as tissue and are, for the purpose of carrying out Radium-penetration Tests, preferable to meat, especially when the latter has to be exposed for long periods, such as 500 hours or more. In such cases the celluloid pieces should, however, be of one homogeneous block, and not be composed of a large number of thin sheets, such as, for instance, photographic X-Ray films, because the large number of air spaces between the films and the many layers of silver salts cause additional resistances to the paths of the β and γ Radiations.

Owing to these various media, erroneous results are recorded. The radiations are, under these circumstances, far too often "broken up," and as "secondary rays" are produced in each case, a scattering of the Rays can be detected in the photograph in the form of "halos."

With a solid block of celluloid—in one piece—the picture is cleaner and the depth of penetration greater, than with an equal thickness composed of separate films, and altogether nearer the density of meat.

I found, however, that the density of the softest celluloid was slightly greater than that of the toughest meat or tissue. Certain kinds of black paper or artificial ebonite are likewise a good substitute for tissue.

I then carried out a series of exacting tests determining the penetrative powers of Slow-Radium versus pure Radium Bromide through pieces of meat, and I consider it of interest and importance to publish the result obtained.

Each piece of meat was wrapped up in a thin gutta-percha envelope and then interposed between a layer of Slow Radium or pure Radium Bromide and an X-Ray plate for irradiation over varying periods.

In the case of Slow-Radium, the irradiation lasted 500 hours, with the result shown in Figs. 24, 25 and 26. The maximum depth of penetration was $\frac{1}{4}$in., and in this case the reduction of the Silver Salts was very feeble indeed. Thicknesses up to $\frac{1}{8}$in. (and sometimes up to $\frac{3}{16}$in.) are, however, considerably affected. In the cases of irradiation with pure Radium Bromide, Figs. 27 to 35 give evidence of the effect of the β and γ radiations through various thicknesses of meat up to $\frac{1}{2}$in. depth of tissue, and I have found that pieces of meat $\frac{3}{4}$in. and even 1in., still allow hard β and γ radiations to penetrate.

The Construction of Volumetric Halos formed in the Process of Irradiation

The planimetric halos formed by the β and γ radiations at the different depths are illustrated in Figs. 20—23 and 24—35. The volumetric dimensions of the complete halos can therefore be constructed and measured. They resemble, with pure Radium Bromide Applicators, a "vortex"

with a powerful or hard nucleus and a shell of weak or soft corpuscles.

This would be a fair description of the complete volumetric Radiation Halo in tissue or meat.

With Slow Radium, the Volumetric Halos are of a quite different shape. When Slow Radium radiations penetrate opaque media, the halo formed is of the shape of a column, the base of which is the area of the Slow Radium Applicator—for instance, a circle. The height of the column (which in this case resembles a cylinder) is represented by the total depth of penetration. In air, the Halo caused by pure Radium Bromide radiations has the opposite shape to that caused in opaque media and resembles the body of an ellipsoid or very nearly that of a sphere. With Slow-Radium and air as the medium, the shape is still that of a column, only with a greater height.

Fig. 36

I photographed the Air-Halos, both of pure Radium Bromide and of Slow Radium, by the following process.

An Applicator $\frac{3}{4}\times\frac{3}{4}$in. in size, containing 15 milligrams of pure Radium Bromide, was placed centrally at the bottom of an inclined X-Ray plate $8\frac{1}{2}\times6\frac{1}{2}$in., and after irradiation for different periods I found on development that a very large area of the photographic plate had been affected, as shown in Figs. 38, 39 and 40.

In the case of $\frac{1}{2}$-hour irradiation, the area of Silver Salts affected was about 7.5 square inches; with one hour's irradiation about 12.5 square inches; and after two hour's irradiation about 20 square inches.

Now, as the area of the Radium Applicator was $\frac{3}{4}\times\frac{3}{4}=\frac{9}{16}$ square inches,

the ratio of $\frac{\text{applicator area}}{\text{affected area}}$ was therefore:

After $\frac{1}{2}$ hour irradiation = 1 : 13
,, 1 hour ,, = 1 : 22
,, 2 hours ,, = 1 : 35

The dimensions of the traceable Volumetric Halo in air, created by the β and γ radiations from a $\frac{3}{4}\times\frac{3}{4}$in. Radium Bromide Applicator were consequently:—

After $\frac{1}{2}$ hour irradiation = 15 cubic in. approx.
,, 1 hour ,, = 33 ,, ,,
,, 2 hours ,, = 67 ,, ,,

Fig. 37

A similar test was carried out with Slow Radium Applicators.

The X-Ray plate was likewise inclined over a strip of Slow Radium Powder which was spread over a metal plate $\frac{3}{4}\times6\frac{1}{2}$in. in size.

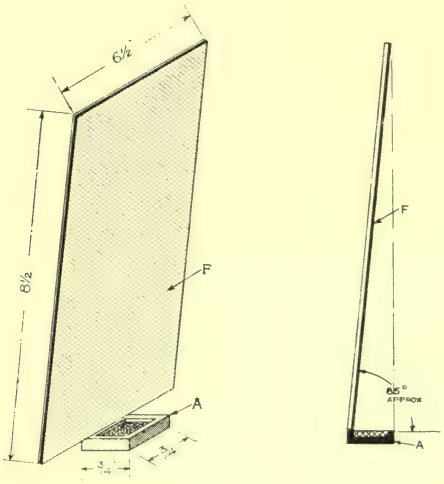


Fig. 36

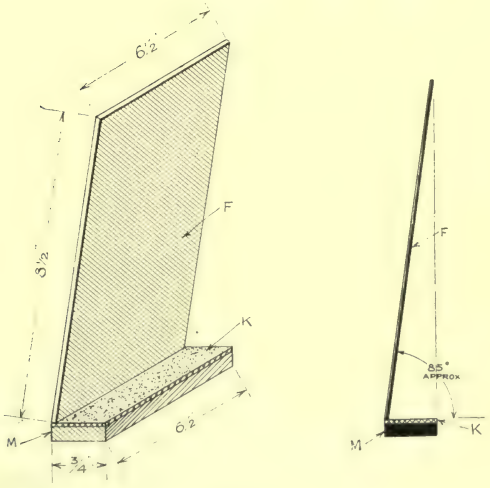


Fig. 37

PLANIMETRIC AIR HALOS.
Produced by Radium Bromide. Illustrations about $\frac{2}{5}$ full size.

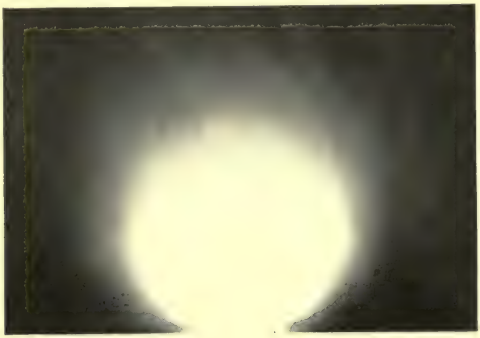


Fig. 38 Irradiation, $\frac{1}{2}$ hour.

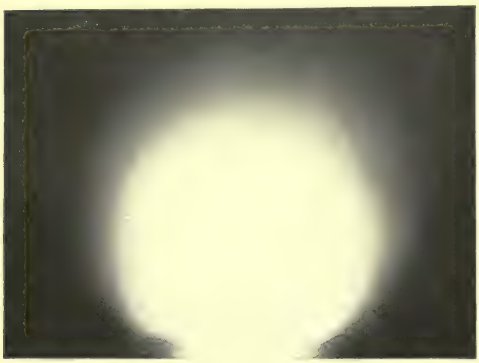


Fig. 39 Irradiation, 1 hour.

Fig. 40 Irradiation, 2 hours.

PLANIMETRIC AIR HALOS.
Produced by Slow-Radium. Illustrations about $\frac{3}{5}$ full size.

Fig. 41 Irradiation, 72 hours.
Effect of α, β and γ Radiations.

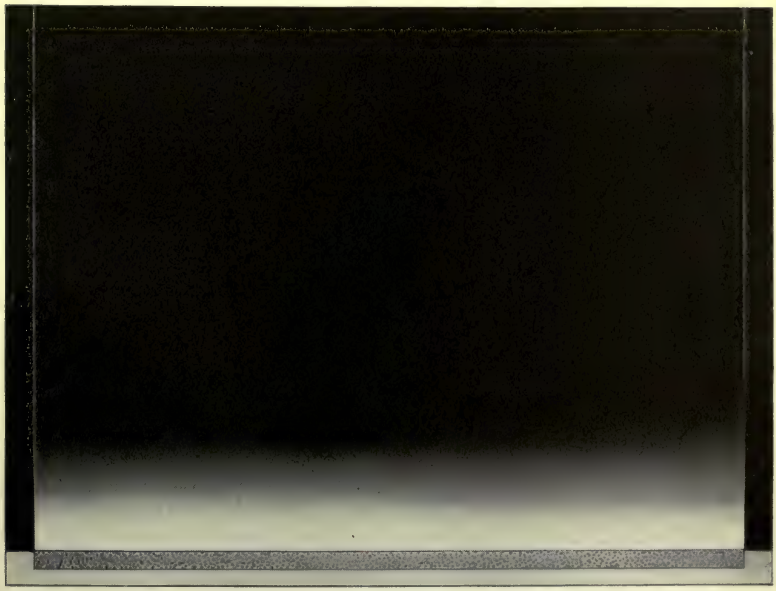


Fig. 42 Irradiation, 72 hours.
Effect of β and γ Radiations only. (α Radiations screened off).

The effect of 72 hours' irradiation is shown in Fig. 41, and proves that the α, β and γ radiations affected the X-Ray plate very evenly.

The total area of the reduced Silver Salts was about 12 square inches.

Ratio of:—

$$\frac{\text{Applicator area}}{\text{Affected area}} = \frac{6.5 \times .75}{12} = 1 : 2.46$$

The dimension of the traceable Volumetric Halo, in air, created in this case is 9 cubic inches.

Fig. 42

In order to compare the Slow Radium Halo caused by the β and γ radiations only, the test described in Fig. 37 was repeated, but the α radiations were stopped by a sheet of notepaper placed over the powder K. Fig. 42 shows the result.

In this case, after 72 hours irradiation, the

$$\frac{\text{Applicator area}}{\text{Affected area}} = \frac{6.5 \times .75}{5.4} = 1.11$$

and the volume of Halo was 4 cubic inches.

Figs. 43 & 44

When applying Slow Radium Applicators to skin or tissue for any length of time, it is most essential to know the total volume of tissue affected by the radiations.

For this purpose I constructed two diagrams, one showing the Planimetric Halo with the shape or section of a vortex, caused by a $\frac{1}{2} \times \frac{1}{2}$in. size pure Radium Bromide Applicator after 1 hours' irradiation of tissue, and the other with the shape or section of a rectangular column and created by a 1in.$\times$3in. size Slow Radium Applicator after 500 hours' irradiation of tissue.

The remarkable difference of the results of treatment with pure Radium Bromide Applicators versus Slow Radium Applicators is best understood when comparing the following calculations in a tangible example.

Let:

A = The superficial area of a skin disease =3 square inches.

B = The depth affected and to be treated $=\frac{3}{16}$in.

n = The number of applications.

t = The time of each application.

Ra = The size of pure Radium Bromide Applicator $=\frac{1}{2}$in.$\times\frac{1}{2}$in.

S = The size of Slow Radium Applicator =1in.$\times$3in.

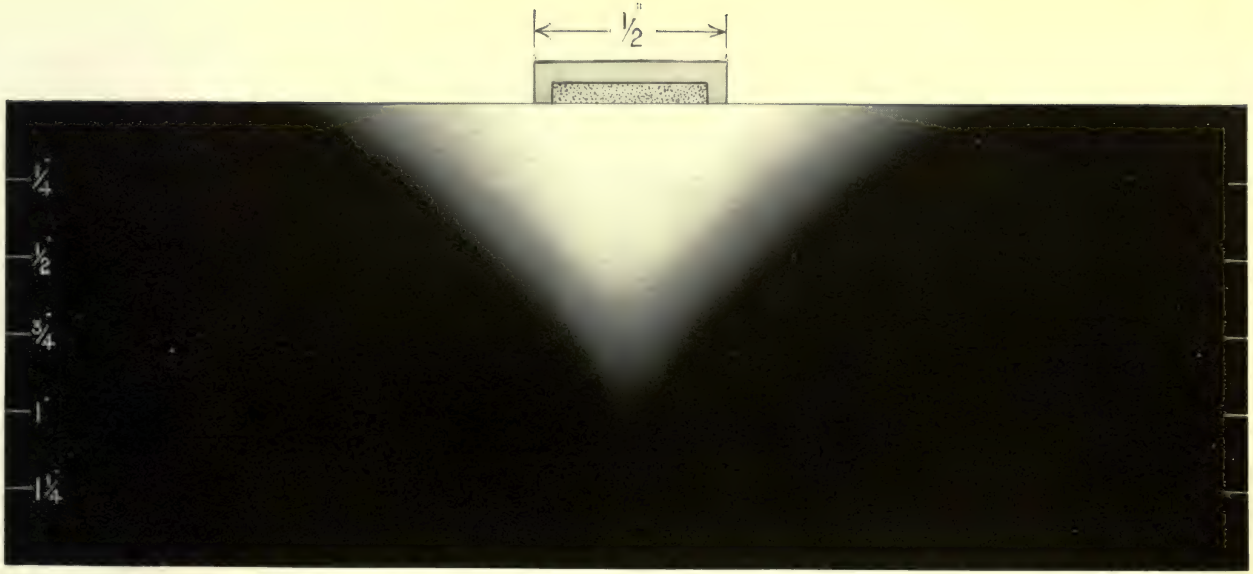


Fig. 43

Planimetric Radiation Halo obtained from a "Pure Radium Salt" Applicator in tissue after 1 hour's irradiation. (See page 69.)

Fig. 44

Planimetric Radiation Halo obtained from a "Slow-Radium" Applicator in tissue after 500 hours irradiation. (See page 69.)

As the superficial area is in this case 3 square inches, there would be 12 irradiations, each of say, 1 hour's duration in the case of pure Radium Bromide, and one application of, say, 500 hours' irradiation with the "Slow-Radium" Applicator.

Let us first consider the dimension of the total volume of the skin disease in this case:—

Volume of disease $= A \times B = \frac{9}{16} = .56$ cubic inches.

The Volumetric Radiation Halos in each case were:—

FIG. 43.—For the pure Radium Salt Applicator with one hour's irradiation = 1 cubic inch.

After 12 applications the total area will be $12 \times \frac{1}{2} \times \frac{1}{2} = 3$ square inches = A, and in this case 12 cubic inches of tissue will have been affected.

FIG. 44.—For the "Slow-Radium" Applicator, with 500 hours' irradiation = .56 cubic inches.

THEREFORE:—

With the pure Radium Salt Applicator the ratio of:

$$\frac{\text{Volume of disease}}{\text{Total Volumetric (pure Radium) Halo}} = \frac{.56}{12} = 1 : 21.6.$$

Whereas with the "Slow-Radium" Applicator, the ratio of—

$$\frac{\text{Volume of disease}}{\text{Total Volumetric ("Slow-Radium") Halo}} = \frac{.56}{.56} = 1 : 1.$$

This conclusively proves that the irradiations from the " Slow-Radium " Applicator affect only the therapeutic cells of the diseased parts, whereas those from the pure Radium Applicator exceed about 20 times its purpose and the healthy living cells below the diseased parts, to a depth of at least ½in., are unnecessarily exposed to the radiations, with effects which are in cases perhaps more detrimental than the disease itself.

CHAPTER VII.

Summary and Conclusion

Slow-Radium as a Therapeutic Agent

I NOW propose to summarize the various results obtained in each test described or illustrated in the previous chapters, and to suggest a tangible application of Slow Radium in the form of a practical "Slow Radium" Applicator for the treatment of external diseases. With regard to treatment of internal tumours by "Slow-Radium" Containers, see pages 86 and 87.

The summary reiterates in concise form the principal characteristics of α and β particles and the γ rays emanating from radium and radio-active substances, their penetrative powers and effects, also my theories regarding the destructive action of Slow Radium Radiations upon tissue cells as compared with that of concentrated Radium Salts.

"Slow-Radium" Applicators

The "Slow-Radium" Applicators I venture to suggest as most suitable for medical purposes

should consist of one or more layers of finely ground Slow Radium Preparations, spread and fixed to the inner surface of sheets made of material which is strong and durable but light in weight, semi-flexible, clean, and harmless to the skin. The finished Applicator should be of such size and shape as to fit snugly and well cover the part to be treated. A kind of " X-uloid " or Celluloid fabric or rubber treated or vulcanized materials formed into a "pad" with or without metal linings or thin metal Applicators, and with a rim or curled-down border, should give good results. Care should be taken to provide an air-space, at least $\frac{1}{8}$in. deep, between the inner surface of the Applicator—where the Slow Radium powder is applied— and the skin. This air gap prevents the powder from touching the skin, and at the same time would induce ventilation by means of small holes around the raised edges of Applicator. When deeper-seated ailments, such as Neuritis, Neuralgia, or perhaps Rheumatoid Arthritis require treatment, the Slow Radium layer is covered by a thin piece of gauze, crepe-de-chine, muslin or similar materials, for the purpose of eliminating the more virulent action of the α particles and weakening the effect of the β radiations at their origin. Applicators of this description are illustrated in Figs. 45, 46 and 47, and Fig. 48 gives a section and general dimensions of "Slow-Radium" Applicators. If any of these Applicators are placed upon an X-Ray plate for about 20 hours, an auto-radiograph is obtained.

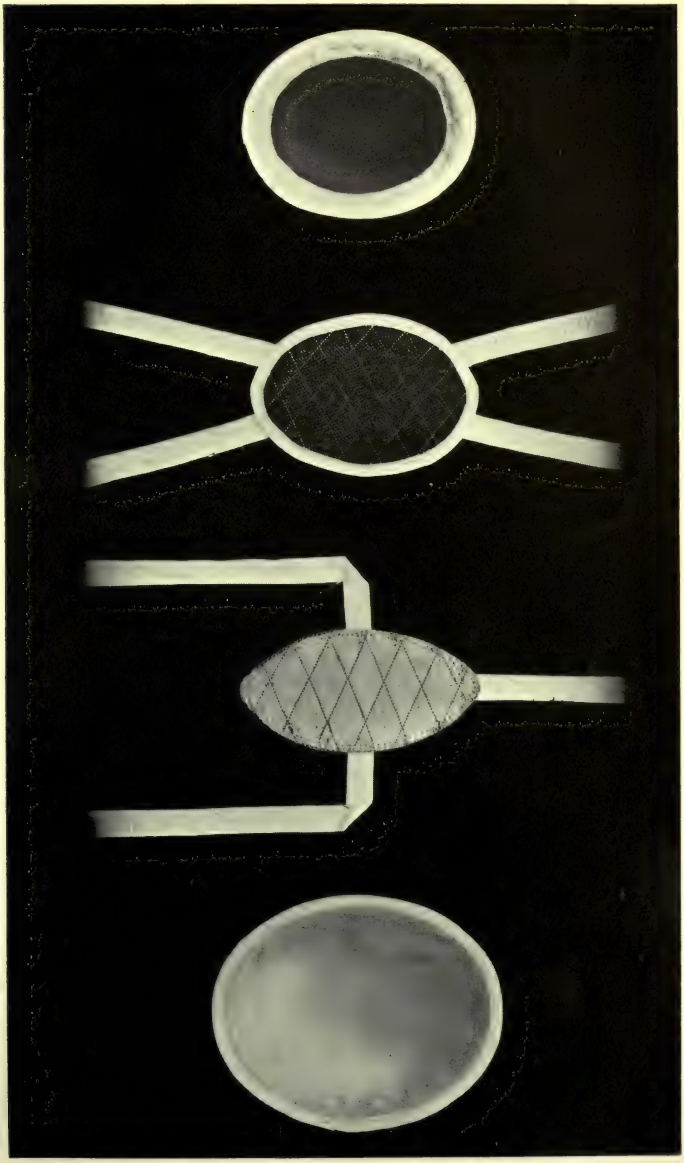


Fig. 45
¼ full size.

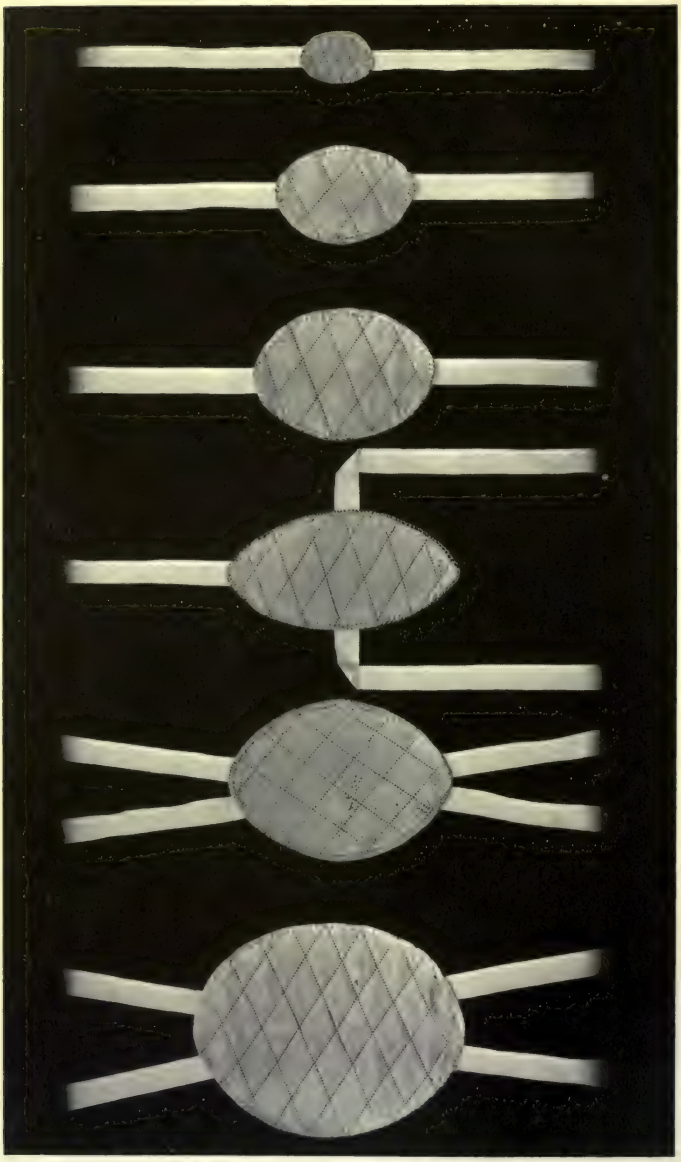


Fig. 46
"Quilted"-Pattern.

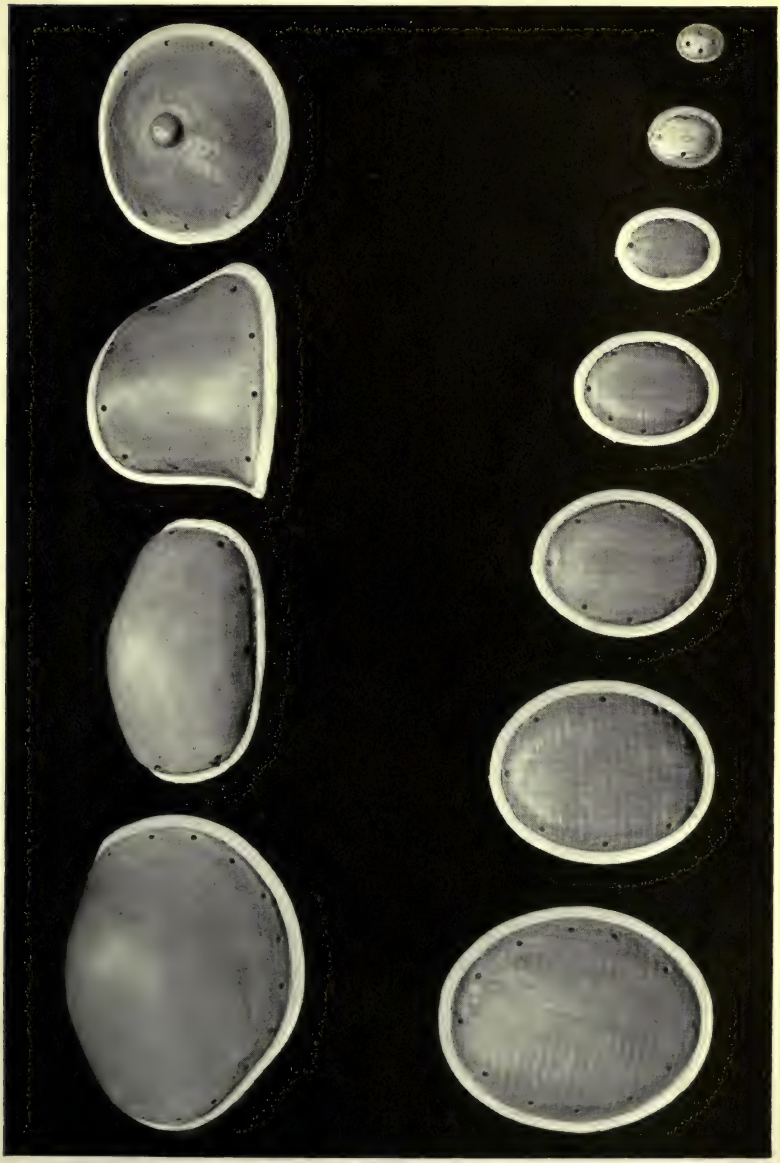
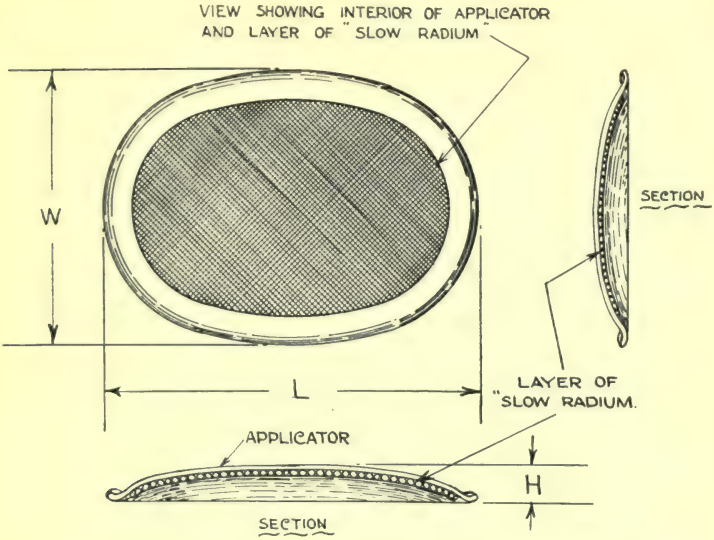


Fig. 47
"Xuloid"-Pattern.



SIZES OF STANDARD KRAMER "SLOW RADIUM" APPLICATORS.

SIZE	OUTSIDE "L" LENGTH	OUTSIDE "W" WIDTH	TOTAL "H" HEIGHT
I	5/8"	1/2"	3/16"
II	1"	11/16"	3/16"
III	1 1/2"	1"	3/16"
IV	2"	1 3/8"	3/16"
V	3"	2 1/8"	1/4"
VI	4"	2 3/4"	1/4"
VII	5"	3 3/8"	1/4"
VIII	6"	4"	1/4"
IX	7"	4 5/8"	1/4"
X	8"	5 1/4"	1/4"

Fig. 48

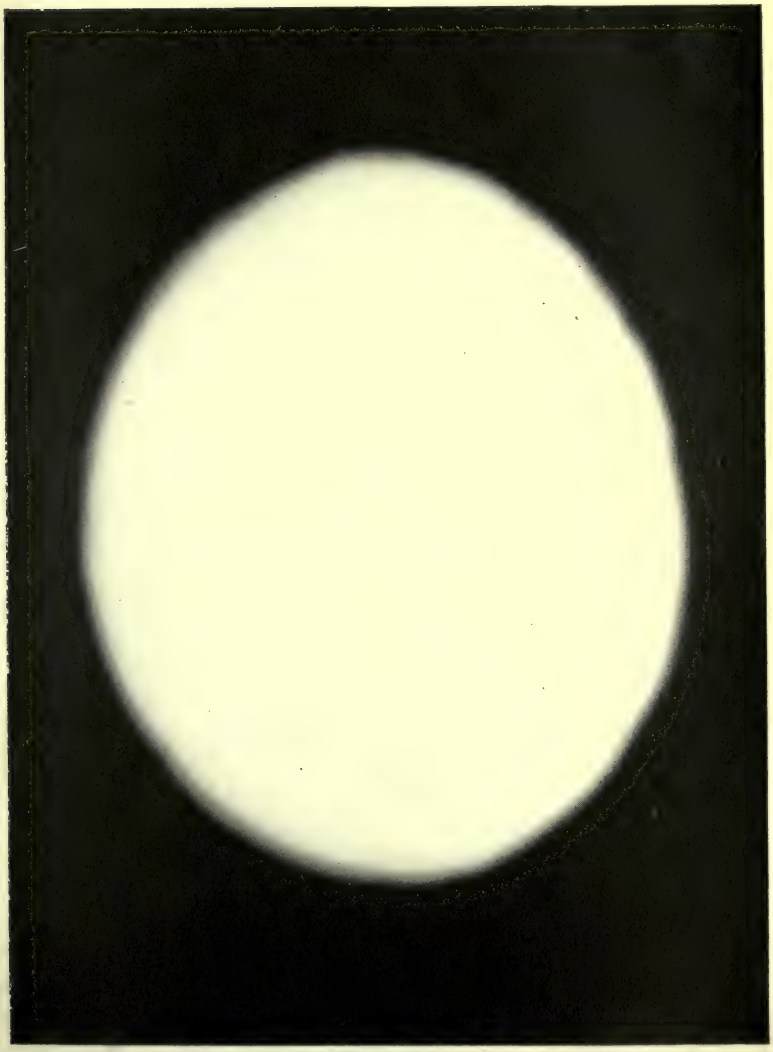


Fig. 49
Auto-Radiograph of an "un-screened" "Slow-Radium" Applicator.
Irradiation area, 24 square inches.

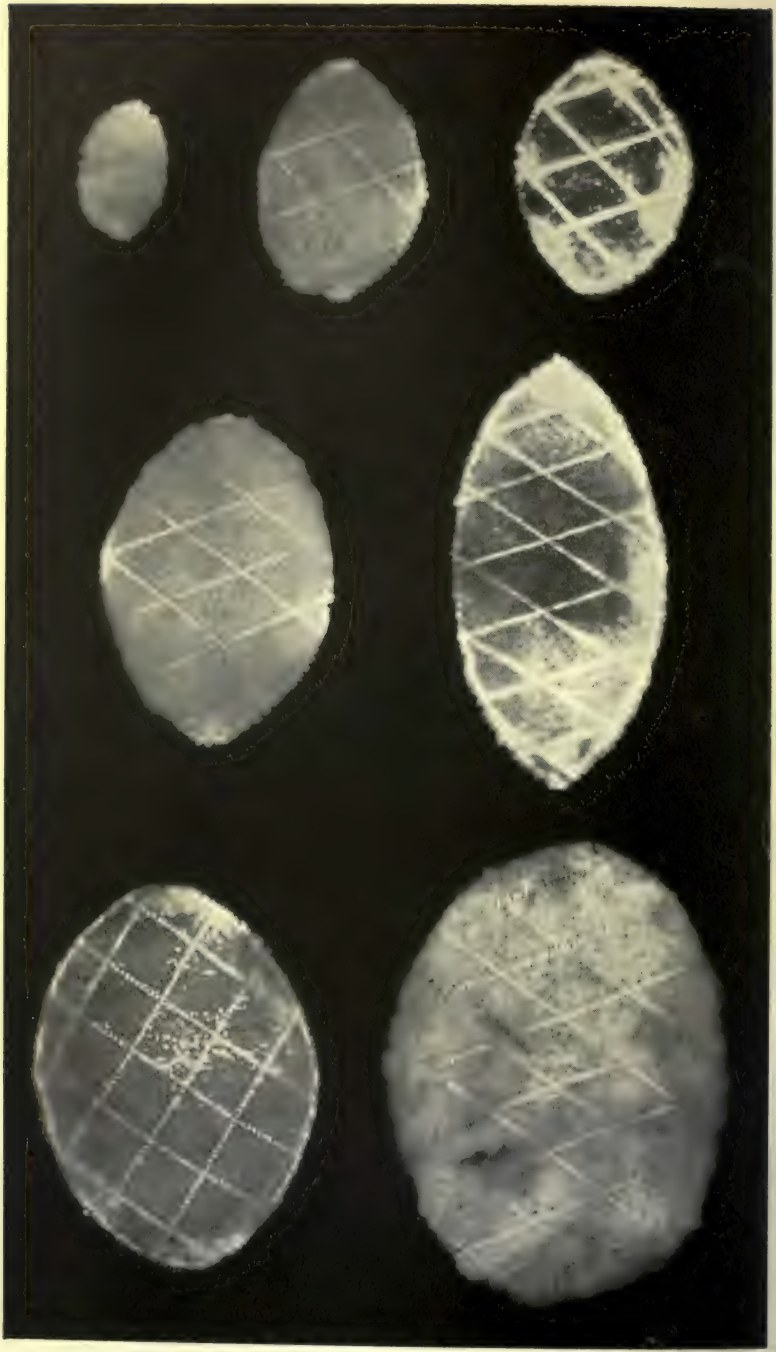


Fig. 50
Auto-Radiographs of "Slow-Radium" Applicators (Quilted pattern).

Fig. 49 illustrates the effect of a standard unscreened "Slow-Radium" Applicator of size VIII. (see page 76), and Fig. 50 the effect of seven Applicators of the kind shown in Fig. 46, which are of the "quilted" pattern, for treatment of muscular or nerve troubles seated below the skin surface.

The effect of the Radiations from "Slow-Radium" Applicators upon the living or pathological Cell is fully dealt with in the next few pages.

Slow Radium Radiations—their dimensions and Therapeutical value

1. The period of activity of Slow Radium, due to the contents of Uranium, Radium and Thorium Salts, lasts uninterruptedly from 2000 to 6000 years.

2. Slow Radium expels α and β particles as well as γ radiations, all and each of which respectively have been traced and measured by photographic and electrometer methods.

3. The α particle is relatively heavy and its speed is consequently the slowest of the three radiations given off by Slow Radium. Its volume is of Atomic Size—about 1.4×10^{-16} c.cm., with a mass of 6.55×10^{-24} grams. It is enshrouded by a positive electrical charge of 3.14×10^{-20} electro-magnetic units, and at the point of leaving the radio-active material, possesses a velocity varying

from 9000 to 12000miles per second in air. It penetrates a layer of air or gas from $1\frac{1}{2}$ to 3 inches in thickness, and is then absorbed or stopped. In other media of denser structure the depth penetrated is smaller approximately in proportion to the density of the medium; tissue, for instance, being approximately 800 times denser than air, practically stops the α particle at a depth of $\frac{1}{800}$ inch, giving up its electrical charge at the point of collision. Owing to its great mass and high velocities, it causes a physical deformation or destruction of the molecules of the exposed matter.

The number of α particles emitted per square inch of Slow Radium amounts to about 4000 to 5000 per second, and thus the α particles represent a formidable bombardment against the object to be irradiated.

4. The β particle is expelled at approximately the same rate per square inch area as the α particle. For comparison, it is interesting to note that, for instance, 5 milligrammes of pure concentrated Radium Bromide expel from a considerably smaller area, say $\frac{1}{8}$th square inch, about 100,000,000 β and at the same time nearly the same number of α particles per second.

   The volume of the β particle is exceedingly minute and, in fact, it is the smallest particle of matter observed up to the present. It measures only 2.8×10^{-38} c.c.m., but its weight, likewise its electrical charge, are very great in proportion to its volume, its mass

being 8.8×10^{-28} grammes and its electrical charge, which is of a negative potential, being equal to 1.56×10^{-20} electro-magnetic units.

The β particle represents the unit element of electricity, and is generally termed the "Electron." The speed of the β particles varies from 60,000 to 160,000 miles per second, and similarly to the α particle, it has a limited range in air. In tissue, after an irradiation of about 500 hours, the β particles from Slow Radium penetrate about $\frac{1}{4}$ inch deep, but after a still longer exposure, these "depth" charges can be traced up to $\frac{3}{8}$ in.

5. The effect of β radiations upon living or diseased cells is twofold:

FIRST.—Owing to their prodigious momentum, the cells in their path are pierced, and therefore, physically deformed or killed. A pathological cell succumbs earlier than a healthy cell, which can resist longer and absorbs more β particles before it is killed. The exact number of cells to be irradiated should be in proportion to the number of β particles bombarding the tissue per unit area, as also should the depth of tissue to be irradiated be in proportion to the penetrative powers of the "Slow-Radium" Applicator. As the bullets of a rapidly firing machine gun when trained upon a small area of a solid block of wood will soon clear a passage for

the subsequent bullets and allow them to penetrate easier and deeper than the first few volleys, so pure concentrated Radium Bromide will soon make a path for the larger number of subsequent β particles, and hence the deeper penetration than is the case with β radiations from Slow Radium. The latter can be compared with bullets from the same machine gun, each fired with the same force but very intermittently (at the rate of 5000 per square inch as compared with 100,000,000 per $\frac{1}{8}$ square inch for Pure Radium), with the result that the "depth charges," after a bombardment of, say, 1000 hours (Slow Radium) or 1 hour (Pure Radium) are in the case of Slow Radium, shallow and evenly scattered, instead of deep and concentrated as in the case of Pure Radium (see Figs. 43 and 44).

SECONDLY.—With β radiations (similar to the α radiations) the effect of the discharge of the electrical energy carried by each particle must be considered of importance. The charge of each α or β particle is given up with probably thermal or electrolytical effects, according to the physical state of the tissue cell prevailing at the moment of its being attacked by the charged particles. The cell—especially the pathological cell—may be in itself electrically stressed —however minutely—with a positive or negative potential.

6. The γ Ray and any other secondary ray produced at the moment of collision of an α or β particle with matter, is of quite a different nature and is more or less an X-Ray. It is generally admitted that the γ Ray is not possessed of any mass at all, nor of any electrical charge. It is a kind of "light" ray or ether motion, but, unlike light, has wonderful penetrative powers into opaque matter. It travels at a speed of up to 186,000 miles per second, and has a particularly short wave length—though the latter is a variable quantity according to the hardness or softness of the individual rays. The effect of the γ Ray upon living or pathological tissue cells must consequently be quite different. There can be no question of giving up a positive or negative charge, however small, as it is an electrically neutral ray, nor can there be any question of an injurious physical collision effect owing to the absence of momentum, as it has no mass.

   An extra large dose of γ or X-Rays may therefore only have similar effects to those of highly concentrated rays of light—probably thermal only.

   The γ Rays caused by Slow Radium are feeble in effect and only slightly more effective nearer the skin than in tissues deeper than $\frac{1}{4}$ inch, and I do not think they possess much therapeutical value.

The action of the "Slow-Radium" Applicator in comparison with the pure concentrated Radium Salts Applicator

	"Slow-Radium" Applicator.	Pure concentrated Radium Applicator.
1.	Continuous, slow and even but definite action, more compatible with the time-element of growth or development of the pathological cell itself.	Spasmodic and super-concentrated action with long pauses between the applications, with the possibility of a healthy cell becoming diseased in the interval and causing new growths, or a diseased cell recovering.
2.	Simultaneous treatment of large diseased areas by large-size Applicators.	Treatment of small areas only, with the possibility of uneven treatment of each small irradiated area at each application.
3.	Easy and effective control of penetrative depth of radiations by calculation and correct selection of strength and long-time irradiation with smaller factor of error.	Short-timed irradiations of unnecessarily deep penetration-depth of radiations, with large factor of error by relatively short over or under exposures.

4. Gradual and slow destruction of all pathological cells up to $\frac{1}{4}$in. depth, without inflicting harm to the healthy deeper-seated cells.	Simultaneous destruction of healthy living cells below the diseased area.
5. Effective use of all α particles where desired.	Absence of α radiations from ordinary pure Radium Applicators owing to varnished surface forming screen.
6. Each patient carries his own "Slow-Radium" Applicator constantly, however large the area to be treated. After treatment, each Applicator can be destroyed so as not to carry infection from one patient to another. Slow Radium can be regained after cremation of the fabric of the Applicator and can be chemically purified, sterilized and subsequently used again. A great many patients can be treated, owing to considerably larger quantities of Slow Radium being available. Much less expensive treatment.	Constant use of same small Applicator on large number of patients for short periods only, owing to scarcity and great expense of highly-concentrated radium preparations.

Figs. 52 and 53 illustrate a number of applications of "Slow Radium" Applicators in various skin and muscular and nerve cases.

Internal Treatment with Slow Radium

With regard to the internal treatment of cancerous growths, Slow Radium has not yet been tried, but I suggest that Applicators, prepared of suitable material, hermetically enclosing the Slow Radium Powder, might with advantage be inserted within or near the growths, irrespective of size. For instance, in a case of the inoperative internal (malignant) tumour, a metal or ceramic Capsule containing a sufficient quantity of Slow Radium, of the shape of a solid or hollow sphere, ellipsoid or disc, might be inserted into the tumour, which should be cored out to receive the "Slow-Radium" Container, similarly as is placed the yoke in an egg. The β radiations emanating from the container penetrate in time—be it 3–6 months, to the depth of $\frac{1}{4}$–$\frac{1}{2}$in., thus killing the pathological cells in the tumour and thus stopping them permanently from advancing the growth (see Fig. 51).

The "Slow-Radium" Container may in some cases be left permanently deposited, without causing harm to the living cells adjoining the outside walls of tumour.

Control Tests carried out in the Slow Radium Laboratory simultaneously with the treatment would show the effect of the irradiation from month to month, and the radiation-penetrations through similar wall thicknesses as those of the actual tumour, can thus be observed.

In such Control Tests a "Slow-Radium" Container of same shape and size and radio-active strength as is inserted into tumour, is placed inside an artificial tumour composed of solid celluloid or fibrous materials and surrounded by X-Ray plates, which are periodically developed, or the Electrometer method is applied.

In conclusion, I cordially invite members of the Medical Profession to collaborate with me in this important research work, and I shall appreciate any criticisms or correspondence concerning the theories I have advanced in this book.

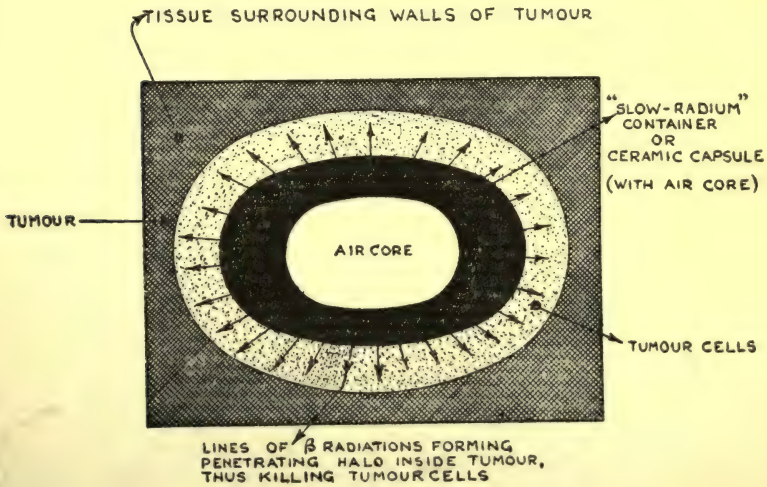

TISSUE SURROUNDING WALLS OF TUMOUR
"SLOW-RADIUM" CONTAINER OR CERAMIC CAPSULE (WITH AIR CORE)
TUMOUR
AIR CORE
TUMOUR CELLS
LINES OF β RADIATIONS FORMING PENETRATING HALO INSIDE TUMOUR, THUS KILLING TUMOUR CELLS

Fig. 51

Diagrammatic Section through Internal Tumour with a "Slow-Radium" Container inserted.

APPLICATIONS
OF
SLOW-RADIUM APPLICATORS
IN SKIN, MUSCULAR AND NERVE CASES.

Small Superficial Nævus on Face.

Slow Radium Applicator applied over same.

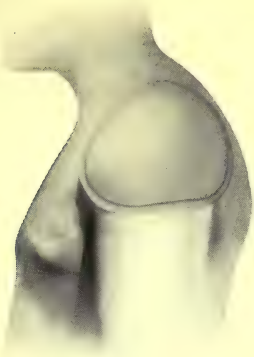
Skin Disease on Back.

Slow Radium Applicator applied over same.

Slow Radium Applicator applied to Lupus on Arm.

Slow Radium Applicator applied over Breast.

Fig. 52



Slow Radium Applicator applied to Shoulder for Neuritis.

Slow Radium Applicator applied to Keloid on Leg.

Slow Radium Applicator applied for Lumbago on Back.

Slow Radium Applicator applied for Arthritis on Ankle.

Warty Growth on Base of Foot.

Slow Radium Applicator applied over same.

Fig. 53

SOME OBSERVATIONS
on the
THERAPEUTIC USE
of
COMPARATIVELY WEAK RADIUM

By
JOHN F. HALL-EDWARDS
L.R.C.P. (EDIN.), D.M.R. & E. (CANTAB.), F.R.S. (EDIN.),
Hon. F.R.P.S. late Medical Officer in Charge X-Ray
Department, General Hospital, Birmingham.
Late Major, R.A.M.C.

RADIUM, owing to its rarity and excessive price, has only been used in practice by a comparatively small number of the Members of the Medical Profession, notwithstanding that it is generally accepted to be a therapeutic agent of very considerable value.

The total amount of Radium at present at our disposal is exceedingly small, and its price is so prohibitive that many who would like to apply it are deterred from doing so. It has long occurred to me that between pitch-blende or radio-active mud on the one hand and pure radium salts on the other, there must exist some point in their concentration at which useful therapeutic results can be obtained.

Rather more than two years back my attention was drawn to some research work which was being carried out by my fellow-citizen, Mr. John B. Kramer. I was much interested in his experimental work, the result of which has been the obtaining of a material which is very highly radio-active as compared with any material previously brought to my notice.

The material now at our command can be prepared in fairly large quantities at a price which is not excessive. Moreover, I have proved by active experiment that it possesses considerable therapeutic efficacy, and whilst it can in no way displace the use of pure Radium under certain circumstances, it has a considerable field of usefulness and perhaps some advantages.

Mr. J. B. Kramer has christened the new material, for want of a better name, "Slow Radium." It is exceedingly stable and gives a constant and regular output of rays. It possesses the principal properties exhibited by the pure salt, namely: the power of reducing the silver salts in a photographic plate—Ionizing the air—the production of phosphorescence and the production of Rays which pass through opaque bodies. It emits α, β and γ Rays, any or all of which can be utilised should it be desired—it also produces emanation.

For use as a therapeutic agent, it is made up in the form of "Applicators" of various sizes, shapes and designs to meet the requirements of individual cases.

As a rule the radio-active material is not allowed to come into contact with the diseased surfaces, and it is not found necessary to varnish it, hence the α rays are not intercepted.

It has hitherto been the custom when a weak radium was required to first produce pure Radium Bromide, by means of fractionisation, and then to dilute it by mixing it with Barium Bromide, but the process of fractionisation is slow, laborious and expensive. "Slow Radium," on the other hand, can be produced quickly in comparatively large quantities, and at small cost. The radio-active output of the material is standardised by measuring its ionizing power, and it can be obtained in varying strengths, each Applicator being accompanied by a certificate setting forth the results of the laboratory tests.

Applicators may be made of any size, so that a large surface of the skin can be irradiated equally all over, and this may be a distinct advantage in some instances.

One of the drawbacks to the use of Applicators containing pure Radium Salts, where a large surface of skin has to be treated, is that only a small portion can be treated at a time, and no matter how carefully the applications are made, it is next to impossible to avoid marking and staining of the skin.

"Slow Radium" can, of course, only be used in certain well-defined cases, viz., in those in which the disease is slow in growth.

It can, however, be applied for a considerable length of time without producing clinically visible and deleterious effects. I have known a patient wear an Applicator nightly for six or eight weeks, the result being, as far as I could make out, the cure of the disease and no other effect.

Whilst I fully recognise the fact that the production of re-action is absolutely necessary, it must not be overlooked that many alterations are produced by the influence of Radium which are clinically invisible. In using pure Radium, reaction is sometimes very intense—on the other hand curative results may be obtained unaccompanied by the slightest degree of visible inflammation.

The term "reaction" (says Wickham and Degreis) "does not necessarily imply a harmful

effect, since no curative action can take place without it."

Reaction may only consist in the healing of the disease, and must depend largely on the nature of the tissues irradiated, and the amount of energy employed. The Rays emitted by radio-active material, as well as by Radium, have a selective action, and in some instances a specific one. There can be not the slightest doubt that, when it is desirable to produce marked reaction, the high-power material should always be used, as it is an open question as to whether lengthy exposure to comparatively weak material produces the same effect as intense radiation occupying but a short time.

In dealing with the subject of Radium Therapy, Mr. A. E. HAYWARD PINCH, F.R.C.S., Medical Superintendent of the Radium Institute, says:—

> *"A Pathological Cell is much more susceptible to irradiation than is the normal one, so that a stimulus which would act only beneficently on a normal cell, could quite well prove destructive to an abnormal one."

Mr. Hayward Pinch points out that a correct appreciation of Radium therapy is largely dependent upon this fact. If an excessive dose be given, the normal cell, as well as the pathological one, may be destroyed, or injured.

It is also pointed out on the other hand, that if too weak a dose be given, the pathological cells may be stimulated to activity, and the size of the growth increased.

*Report of the Radium Institute for the year 1920, by A. E. HAYWARD PINCH, F.R.C.S., Medical Superintendent (p. 12).

In my experiments with "Slow Radium" so far, I have failed to note any stimulation of the pathological cell. I may say, however, that I have made no tests as to its therapeutic value in malignant disease.

"Slow Radium" is certainly worthy of a prolonged trial in chronic superficial cutaneous diseases.

Not now being attached to a Hospital, I have few opportunties of testing its results. It will be found useful in such diseases as Eczema, Psoriasis, and in very superficial nævi in various pruriginous and other skin affections, in mild and commencing Lupus and in the treatment of boils, carbuncles, etc. I have tried it in a case of Keloid with highly satisfactory results, also in thickened scars and pruritis. Some of the best results have been achieved in the treatment of Neuritis and persistent Neuralgia. There are a large number of other conditions in which "Slow Radium" may be used with advantage, and my main object in writing these observations is to invoke the aid of dermatologists and other members of the Medical Profession in giving the new material a trial.

Early in the history of Radium, various waters and substances in which the most minute quantity of radio-active material was found to be present, met with over-flowing praise, and their value as therapeutic agents was thus exaggerated beyond reasonable limits. The fact that the waters of certain Spas contained Radium could not have enhanced their therapeutic value since they must have always contained it.

Compared with these substances, "Slow Radium" is many thousand times stronger. It is capable of affecting a photographic plate wrapped in double paper wrappers in less than two hours, and it will deposit the whole of the available silver within forty hours.

Experiment has shown that the Rays emitted from "Slow Radium" are capable of passing through a large variety of opaque materials, and tests are being scientifically carried out in order to discover the limits of its penetrative power in animal tissues.

My experiences in the use of the strongest material at the time available are limited, but I should like here to give details of a few cases in which valuable therapeutic effects have been produced.

NEURITIS. A gentleman consulted me with Neuritis at the back of his neck and in his right shoulder. He informed me that he was in the habit of daily motoring for long distances in an open car, and that whenever it became necessary for him to put up the hood on account of wet weather, he always, on the following day, had a return of the pain, which sometimes lasted as long as a week. He attributed the Neuritis to the back draught caused by the hood.

On the first two occasions I applied Ionisation, which gave him considerable relief. On the third occasion I obtained for him a "Slow Radium" Applicator. This he wore for several weeks, and informs me that for some months he has had no further attacks.

KELOID. A lady consulted me with a Keloid some two inches in length, and over half an inch broad at its widest part, situated upon her chest. I can obtain no history of her having received an injury or of having had a sore in this position, and she can only suggest that it followed the wearing of a brooch or pendant. There was much thickening, a part of the growth being raised more than one-eighth of an inch from the skin level.

I first treated it with a small Applicator containing pure Radium Bromide, and by this method of treatment I reduced its thickness by more than half.

She was exceedingly anxious that I should remove the growth without leaving any visible scar, so I had made for her a special Applicator containing "Slow Radium." She has worn this on and off for four months.

The last time I saw her the skin appeared normal, with the exception of a slight blush occupying the position where the growth was the thickest. The skin which was previously involved is of the same colour as that surrounding it, and is not white like that which frequently follows intensive treatment.

DERMATITIS. A lady consulted me with a chronic dermatitis of the right cheek, which commenced near the ear and extended half-way across the cheek. It was only a faint blush, and had been present for over a year. She had tried all sorts of remedies without effect. To the

touch there was a mild sensation of brawniness. She wore a "Slow Radium" Applicator for about three weeks, when the whole of the upper part disappeared. She then left the district and I have not seen her since. The case was sent to me as one of Lupus.

The above cases will suffice to prove that the material exhibits useful therapeutic properties.

Taking into account the reports recently circulated as to the deleterious effects produced as the result of changes in the blood, and effects upon the nervous system, by doctors and nurses who apply Radium for therapeutic purposes, I shall necessarily be asked to what extent the continuous wearing of these Applicators affects the system.

I can only say that in the cases quoted, and many others, I have failed to note any deleterious effect, nor have I had any complaint other than that arising from the form of the Applicator, and the method of fixing it in position.

The Experimental Applicators have been so constructed that their radio-active output could be electrically measured from time to time. They have, however, proved so constant in their radio-active output that this is no longer necessary. The Applicators are, therefore, much lighter in weight, and can be more easily and comfortably worn by the patients.

My interest in this comparatively weak Radium is purely a scientific one, and the results already

achieved inspire me to urge their trial by dermatologists and others in some of the chronic and intractable skin diseases which they, from time to time, meet with in the course of their practice.

APPENDIX

W. BAIN, M.B., B.S. Lond., M.R.C.S., L.R.C.P., Lond.,
Brook House, Minehead, Somerset.

NEURITIS OF SHOULDER AND ARM.

MAY 26TH, 1921.

The patient suffered acute pain over the Trapezius and shooting pains extending down the fingers and the inner side of the hand. There was considerable limitation of movement owing to the pain. The patient had been treated for two years with Radiant Heat, Ionization and Massage. There was slight improvement under these various forms of treatment. The radio-active material was applied over the back from the second dorsal, extending upwards and forwards to the Sterno-clavicular Joint and outwards to the Acromic-clavicular Joint.

After six weeks' treatment the patient expresses himself as being better than he has been at all for the last two years. There is no pain on movement and the sensation of the fourth and fifth fingers and the inner side of the hand is normal. There is still slight aching after movement. Treatment is still continuing.

SEPTEMBER 11TH, 1921.

Neuritis of the shoulder and arm is practically well.

LUPUS OF THE NECK.

MAY 26TH, 1921.

Operated on at St. Thomas's Hospital and treated by Light at Middlesex Hospital over a period of two years. A triangular patch under the left jaw, base of triangle measuring three inches. The area was purple and thickened with several large Keloid lumps. The Radio-Active Applicator was applied over a period of seven weeks. At the end of that time only one Keloid mass, with an area of a shilling, remained. The rest of the area was pale, and had the appearance of old scar tissue. The Keloid mass is still being treated.

SEPTEMBER 11TH, 1921.

The case of Lupus is practically cured. The small Applicator last sent being for the remaining nodule in the anterior portion of the scar.

E. T. SELKIRK, M.B., CH. B. (Ed.),
City Mental Hospital,
Winson Green, Birmingham.

T.B. AET. 69.
JULY 10TH, 1921.
Warty growth on third finger of left hand, 2 inches long and 2 inches wide. She had had this for six months. The "Slow-Radium" Pad was applied and in five weeks' time the growth had diminished in size, the redness of the skin had gone, and the surface of the growth, instead of being rough with numerous small warty processes on it, has become smooth. Treatment is still going on.

The patient had a similar growth 5 inches long and 4 inches wide higher up on the same arm. A "Slow-Radium" Pad was applied at the same time as in the first case. The inside of the growth has healed and the edges have much improved.

SEPTEMBER 9TH, 1921.
The right edge has now healed.

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